MICROBE

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Minimizing the influence of coronavirus in a built environment

MICROBE

O2/A2. Analysis of former concepts, models, methods, and theories of MICROBE

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1. Analysis of human emotions and/or experiences in a built environment

More than half of the world's inhabitants now reside in towns, making the development of healthy city environments a main policy priority [1]. In the opinion of Shoval et al. [2], individual emotional connections with a city's environment have been of vital importance to city researchers for decades. A city's physical, social and cultural aspects determine a person's emotional involvement with a city environment. Various research studies [3, 4] propose that a city's environment (its architecture, land use mix, public squares, parks, built features, polluted areas, rubbish, the quality of the built environment, manufacturing zones and traffic flow) plays an important role in human emotions, moods and mental health, in conjunction with individual and social factors. Gong et al. [4] hold the opinion that a city's environment affects people on an individual/personal level (based on individual perceptions) and due to the effects of public spaces. Rapoport [5] defines the built environment as a form of "nonverbal communication", and finds that individuals use tools to interpret its meanings. Carmona [6] has emphasized that the perception of an association between humans and their physical environment is a vital constituent of city planning.

Efforts to assess the effect of a city on human emotions, from both a subjective and objective point of view, have involved the development and application of various methods and tools over recent decades. Analyses of human emotions have been undertaken by an entire array of researchers, and subjective studies include those by Kim et al. [7], Solymosi et al. [8], Resch et al. [9] and Birenboim et al. [10] while objective studies have been conducted by Sagl et al. [11], Birenboim [10], Birenboim et al. [12], Zeile et al. [13] and integrated studies by Birenboim et al. [12, 14] and Shoval et al. [15].

Subjective studies of human emotions/experiences in an urban context have been performed by applying qualitative methods such as self-reports, interviews, observations, questionnaires and diaries, in order to register the subjective experiences of individuals in their usual settings. For example, self-reports might encompass methods such as the Ecological Momentary Assessment, the Pleasure–Arousal–Dominance scale and the Experience Sampling Method. Russell's circumplex model of emotion [16] can aid in the evaluation of a self-report (as per the Pleasure–Arousal–Dominance scale), and has been widely used in such studies [7]. Loiterton and Bishop [17] of the Royal Botanic Garden in Melbourne sought to examine subjective feelings such as boredom, fatigue and hunger, and developed questionnaires focusing on public spaces, applying these data to make forecasts about people walking in the garden.

Objective studies of human emotions and/or experiences in a built environment have involved the application of biometric methods and systems (blood pressure, body temperature, heart rate, skin conductance, pupil size, blinking and others). A number of researchers have looked at ways to make ambulatory physiological sensing part of urban planning [10, 13, 14, 18]. In their efforts to integrate ambulatory sensing within urban planning, Nold [19], Sagl et al. [11], Zeile et al. [18] and Resch et al. [20] have relied on fundamental theoretical and methodological approaches. Advanced technologies and tools now offer more effective ways to focus on residents [18]. Data related to emotions can also offer a different way to validate the monitoring of public spaces [20]. Many researchers use wearable electronics (smartwatches, Google Glass, computerized contact lenses, wristband sensors, intelligent textiles, wearable sensor patches) to conduct unbiased affective, emotional and physiological studies. Many of these devices were first imagined in science fiction and mainstream films.

When we know how individuals respond to environments via their emotions, we can begin to understand how people engage and interact with spaces [21]. Based on this, designers, planners

and managers of public spaces can measure people's responses to various different stimuli [22] within the built environment [23]. The combined effects of various environmental stimuli produced through interaction, and their power to induce the desired emotions and behaviors, need further study before they can be fully understood [24]. Hence, there is a need to study the emotional reactions of human beings to the everyday stimuli that can affect the senses of people living within and using different spaces [23].

Human emotions have also been studied using an integrated approach [12, 14, 15, 25]. For instance, Pettersson and Zillinger [25] examined the positive and negative feelings of contributors during the 2008 Biathlon World Championship held in Ostersund, Sweden, with the help of tracking technologies and questionnaires. The Huss Index, developed by Daly et al. [23], combines ethnographic methods (i.e. interviews and sensory mapping) with measuring biometric technologies in an attempt to discover correlations between the subjective feelings of the participants and their statements about their environmental experiences, with their objective physical and emotional states tracked in real time and in a natural environment [23].

Mehrabian and Russell [26] determined that environmental perceptions inspire various emotions, and that these emotions affect a person's responses to the environment, either positively or negatively. The aforementioned studies and those presented below have examined different types of emotions (happiness, sadness, anger, surprise, fear, disgust, anxiety, neutral, etc.), moods (e.g. depression) and feelings (psychological stress and distress). Researchers have analyzed the impact of a city's social, built and physical environments on human happiness [9], sadness [9], anger and disgust [9], surprise [7, 11], fear [27], depression [28], psychological distress [29], anxiety [30], mental disorders mixed with anxiety and depression [31] and psychological stress [29]. There have also been several studies analyzing cities and their built environments in terms of the effects of pollution on human emotions, stress and mental health [32]. What should a built environment be like, in order to generate positive experiences for people, reduce the negative emotions of its residents and bring about feelings of emotional comfort? For example, Vischer [33] and Daly et al. [23] hold the opinion that in order to provide psychological comfort within a city or a built environment, there needs to be better satisfaction of basic human needs and individual perceptions and a sense of belonging and satisfaction within existing public spheres.

Current research involves measurements of the integrated objective and subjective dimensions of emotions at two levels (individual perception, and the perception of the city and built environment). Individual affective, emotional and physiological tests [34, 35] have also been conducted previously. The project coordinator and partners have developed an Affect-Based Built-Environment Video System (MICROBE) based on the aforementioned literature sources and their long-term personal experience in this field. Within the framework of the H2020 ROCK (Regeneration and Optimization of Cultural Heritage in Creative and Knowledge Cities) project, the MICROBE method and system were developed. As part of the ROCK project, studies are being carried out with a broader scope from the perspective of public spaces in comparing with previous similar studies [7-15, 17-25].

Significant contact-based biometric investigations are being conducted in built environments, and have also been carried out across the world [8-20]. The term 'contact-based investigations' means that sensors have direct contact with the person under analysis. The analysis of these important investigations [8-20] involves comparing a small amount of data according to the number of metrics.

Daily fluctuations in the rhythms of human behavior and physiology, which occur due to light and social cues, show remarkable differences due to their individuality [36]. Diurnal rhythms, either under constant conditions or in idealized light-dark surroundings, have been the focus of many

research studies, although the effects of social pressures such as timetables for employment and education on the daily and seasonal activity rhythms of individuals have attracted relatively little attention, and few studies have been carried out in this area.

Physiology organization on a timely basis is critical for human health. Sleep–wake behavior, hormone secretion, cellular function and gene expression are systems that recur in strict rhythms on a twenty-four-hour basis [37]. A biological network of fundamental value for harmonizing human biology with its surroundings, in the opinion of Yang et al. [38], is the molecular clock. This clock affects the daily fluctuations in human activities, body temperature, mood, blood pressure and hormonal secretion patterns.

Surveys assessing diurnal collective emotions have typically been carried out by administering questionnaires to several dozens or hundreds of people. Very large scales have been available currently due to big data of written texts on the Internet relevant to collective emotion analyses [39]. An analysis of affective cycles in global social networks has been successfully conducted over the past 10 years using Twitter [40-43], Facebook [44] and blogs [39]. As reported by Liang and Shen [45], social media platforms have shown regular daily patterns of user activities in prior studies. Clear cycles based on weekly and seasonal behaviors appear as collective emotions. Sano et al. [39], who spent 10 years examining collective emotions based on 3.6 billion blog articles originating in Japan, have identified such periodic behavior using a dictionary-based method. Dzogang et al. [43] conducted another study that involved taking samples of Twitter contents in the United Kingdom at hourly intervals over four years. Their work revealed a strong, diurnal rhythm in most psychometric variables, and showed that 85% of the variance across 24-hour profiles could be explained by only two independent factors. Dodds et al. [40] also examined expressions made on Twitter, finding temporal variations in happiness and information levels when viewed on hourly and annual scales. Their dataset consisted of over 46 billion words making up nearly 4.6 billion expressions, which were posted by over 63 million individual users over 33 months. Pellert et al. [44] empirically tested a computational model of affective dynamics, studying a large-scale dataset of updates on Facebook statuses by employing text analysis techniques. After stimulation was applied, affective states returned exponentially to an individual-specific baseline. The quantification of these states is as valence and arousal. A somewhat positive valence value and a moderate arousal point below the midpoint are, on average, at this baseline [44]. The two fundamental dimensions of mood, i.e. positive affect (PA) and negative affect (NA), and their diurnal rhythms were studied by Clark et al. [46] who found that there was significant diurnal variation in PA but none in NA.

Updated outlooks on collective human behaviors are now part of the data available to people involved with the Internet, and more and more people are partaking of such innovations in current times. The identification and analysis of collective diurnal and seasonal emotions were a previously non-existent area of research, as social media have taken off in popularity and become widespread only over the last 10 years or so [39]. Policies regarding actions and decision making and their diurnal rhythms require not only the application of extracted and traced collective emotions [36] but also analyses of language changes [43], hedonic behavior, music [47], natural disasters [39], reproductive cycles [48], and so on. Constant diurnal rhythms in policies regarding actions and decision-making have also been discovered by Leone et al. [36], who report that in the morning, actors are likely to follow policies focused on prevention and involving slower, more accurate decisions. Later in the day, actions tend to focus more on promotion, involving faster but less accurate decisions. Language undergoes dramatic changes between day and night, as conclusively shown by Dzogang et al. [43]. These changes reflect the differences in the concerns of individuals and their fundamental cognitive and emotional processes. Major changes in neural activity and hormonal levels give rise to these shifts [43]. A pattern of monotonically improving, weekly returns characterizes the day-of-the-week

effect, as revealed by the enormous amount of evidence found by Zilca [49]. There is a day-of-the-week effect, which can be explained by behavior. A monotonic improvement in mood is seen over the course of a week [49]. One hypothesis for this is based on biology, and claims that human reproductive cycles adapt to seasonal cycles that are hemisphere-dependent. Another hypothesis is cultural, and claims that cultural factors such as holidays primarily cause this variance in conception dates [48]. There is a strong relevance of a weekday to long-short anomaly returns. An analysis by Sano et al. [39] examines collective emotion caused by natural disasters. One example is in Japan, showing much tension in April when school starts, which is likely to be the reason. Again, in Japan, whenever there are consecutive holidays, the incidence of suicide increases [39]. Park et al. [47] studied the diurnal and seasonal patterns in affective preference by analyzing global music streaming data.

Global research [50-53] indicate that emotions play an exceptional role in decision-making (see Method). The studies conducted as part of this research are innovative, since this is the first time biometric data have been gathered remotely on a large scale for the testing of collective emotions. The purpose of this research is to establish human affective rhythms (diurnal rhythms and seasonal patterns).

Until now biometric research has been executed on a large scale, not remotely. Various vendors, including Fitbit, Microsoft, Google, Android, Apple and Samsung, adopt particular approaches to the way continuous data, such as skin temperature, heart rate and others, can be collected from wearables, including from sensors, into third-party systems [54]. Fitbit (an activity tracker) followed with analogous research. This was the biggest ever collection of heart-rate data with more than 150 billion hours of data taken from users of the widespread fitness tracker [55]. Various Emotion APIs including Microsoft Azure, Affectiva, Face Reader by Noldus and the Kairos API execute emotion recognition and analysis from the facial expressions in any image or video. For example, Affectiva has examined 3,289,274 faces worldwide, both online and offline [56]. AffectNet, a large-scale facial expression image database, includes one million facial images along with the labeling of expressions, valence and arousal [57].

Over the course of the ROCK project, MICROBE (an Affect-Based Built Environment Video Analytics) has accumulated over 200 million anonymized data points by remote means, and this number continues to grow. Several synonyms are used in the literature for contact-free biometric measurements, such as contactless, stand-off, distance or non-contact biometric measurements. MICROBE expands the important investigations of the built environment described above [8-20] by analyzing the large number of variables for a large number of data collected by remote means.

2. Screening, diagnosing, monitoring and analyzing COVID-19 by applying biometric and AI technologies

Research in the areas of large-scale screening, diagnostics, monitoring, analysis and COVID-19-based categorizations of people by symptoms have wrought much honor and recognition to numerous scientists and practitioners for their achievements. Their applications for accomplishing such work includes wearable technologies, early warning systems, biometric monitoring technologies, IoT based systems, Internet of Medical Things and other tools pertinent to the COVID-19 pandemic.

Modern healthcare methods and systems have suffered a never before experienced crisis by the emergence of the COVID-19 pandemic. Remote monitoring became a primary means of

healthcare provision for safeguarding millions of Americans as a result of the resource constraints, when this pandemic hit its first peak [58].

Symptomatic people, as researchers have discovered, often indicate a drop in heart rate variability, although their resting heart rate and breathing rate rise. So long as measurements could capture such changes in a person, health can be treated as much as a week prior to a potential reporting of such disturbing symptoms. As many as 72% of the people suffering from COVID-19 most often report feeling fatigue. The other symptoms frequently reported by patients were headaches by 65%, body aches by 63%, a loss of taste and smell sensations by 60% and coughing by 59%. Researchers have discovered that as few as 55% of people ailing with COVID-19 reported having a fever, which is alarming, because merely temperature screening may be insufficient to denote such an infection [59].

Clinical care as well as the research in this field are bound to adopt remote monitoring permanently. The needs for convenience and security have opened opportunities for greater use of Telehealth and remote real-time monitoring of vital signs. Measurements of vital signs can be taken safely and conveniently within people's homes by employing biometric monitoring technologies (BioMeTs). BioMeTs can serve a number of clinical requirements for adequate responses to the COVID-19 pandemic. It can be applied for assisting initial physical evaluations of people, contributing to the triage of patients indicating COVID-19 symptoms and even for monitoring patients after their discharges from a hospital to lessen the risk of readmission. BioMeTs currently come in numerous versions for remote collections of vital signs for many days. The signs collected include body temperature, heart rate, BP, blood oxygen saturation (SpO2) and respiratory rate. These are needed for the overall care of people suffering from COVID-19. A number of research studies employ wearables like WHOOP, Oura Ring and smartwatches. These are in appropriate positions to undertake investigations regarding the use of BioMeTs measurements, not only for early detection of the illness but also as a means for predicting the possible severity of it [60].

While people are isolated during this pandemic, there is the potential of discretely applying Doppler radar for data on breathing-related information. This adapted, battlefield radar for biomedical purposes has the ability to view people's bodies beneath their clothing in order to record their breathing frequency rates, heart rates, tidal volume and pulse pressure. The aim of such testing is finding ways to ease lockdowns meant to restrict coronavirus infections. Furthermore such technology for sensing respiration in an inconspicuous manner is capable of monitoring pulse, heart rate variability and respiratory rates. Thereby early-stage symptoms of COVID-19 can be easily captured [61].

The spread of coronavirus infections can also be greatly curtailed by the use of wearable technology. This technology can gather numerous sorts of data including heart rate, blood pressure, body temperature, ECG, lung sound, levels of blood oxygen saturation (SpO2) and the like [62].

The physiological stress on the body caused by the COVID-19 virus rises. This generally causes a rise in heart rate as well. Wearable remote monitoring systems, once upgraded, could offer healthcare solutions that are cost-effective and timely. Furthermore these offer an entire range of help over the course of managing COVID-19 illnesses for patients, covering early warning systems for preventative purposes, diagnosis, treatment and, finally, rehabilitation [61].

Health monitoring must track the primary metrics of people. The IoT based system has been recommended by Tamilselvi et al. [63] for this purpose. The system is fully capable of tracking body temperature, heart rate, eye movement and percentage of oxygen saturation. Furthermore this system offers integrated heartbeat, SpO2, temperature and eye blink sensors to handle the gathering of data. The Arduino-UNO has also been recommended as a processing device.

Physicians must identify clinically meaningful changes in vital signs when they monitor for COVID-19 or any other changes in health status. Various technologies are potentially able to assist in such efforts to denote health deviances from their normal variations. Deviances can be due to biological variability, time of day, food and drink, age, a person's exercise or underlying physiological conditions [64 – 66].

The accuracy of a wearable is not the only consideration involving the product. People are not likely to use a product if wearing it is uncomfortable. To name two examples, sticky adhesives and bulky smart clothing will simply never be adopted by all people, whether they are patients or not [60].

Management of the medical and logistical aspects of the COVID-19 crisis evidently required a real-time, command and control tool for hospitals. The requirement for maximizing the efficiency of hospitals is a system capable of integrating clinical data on patients, medical staff status, inventories of critical clinical resources and asset allocations into one dashboard. The development of the CoView™ System addressed such a goal. It was able to join together defense concepts, big data analytics and health care protocols. Decision-makers can use this system to respond efficiently and optimally, because this system provides needed evidence pertinent to the status of all COVID-19 patients at all hospitals and admission facilities. The system is capable of analyzing aggregated data from patient monitors and electronic charts by employing artificial intelligence algorithms. It then permits appropriately alerting medical staffs regarding a worsening health among certain patients on an individual basis or analyzing treatment procedures at specific hospitals. High-level experts acting as professional advisors are able to monitor every hospital for its current situation along with its schedules of treatments and their effectiveness. Thereby such experts can assist hospital staffs everywhere in the country as required. Hospital occupancy, patient conditions, logistics and other similar factors must enter into a centralized, real-time review to establish the status of hospitals. Effective decision-making and resource allocations fundamentally rely on this sort of overview [67].

One monitoring technology used for measuring breathing and heart rates involves thermal imaging techniques [68]. Others include breathing dynamics [69] and respiration rate [70]. A recommendation offered by Jiang et al. [71] involves use of a portable non-contact method. It is meant to screen the health conditions of people by analyzing respiratory characteristics even while people are wearing their face masks. This is possible with the application of a device mainly consisting of a FLIR one thermal camera and an Android phone. Its use includes monitoring possible COVID-19 patients by inspecting them in practical scenarios such as in hospitals or for pre-inspections at schools. Health screenings were performed by Jiang et al. [71] by virtue of combining the RGB and thermal videos, which they acquired from the dual-mode camera and from deep learning architecture. A respiratory data capture technique was first accomplished by Jiang et al. [71] on people wearing face masks by employing facial recognition. Next, they applied a bidirectional GRU neural network with an attention mechanism to the respiratory data to arrive at a final health screening result. Respiratory health status can be recognized to an 83.7% accuracy rate on the real-world dataset, as the results of validation experiments indicate regarding the Jiang et al. [71] Model.

When it comes to predicting respiratory symptoms over the course of COVID-19 progression, Dhanapal et al. [72] recommend a Pervasive computational model with wearable devices system. Breathing rate, inhale–exhale rate, temperature ratio and shortness of breath the focus of the information examined. Deep-learning computational models depict and process the difference between normal and abnormal breathing conditions. This recommended approach gathers data on how far away people are from the sensory devices, regardless of the cloth used to construct the

facemask, the angles of measurement and other information, which is appropriate for classification purposes. The results of the recommended system are at a 94% rate of accuracy. Their precision, rate of recall and F1-measure display as averages in the performed experiments. Automatic encoders obtain possible traits by virtue of the machine-learning algorithms. These are possible due to the simplicity of large-scale screening and monitoring as well as their being requirements [72].

The three levels of severity of the COVID-19 viral infection, according to the categorizations by the latest clinical research, are mild, moderate and severe. Different respiratory symptoms are observable at each level, ranging from, e.g., the dry cough occurring in mild infections, to shortness of breath in moderate illnesses and onward to the severe dyspnea and respiratory distress, when the respiratory frequency 30 breaths/min, which is also known as tachypnea, in cases of severe illness [73]. Despite the three categories, actually, all such breathing deviations progress to abnormal articulation variations. Subsequently, the employment of automatic speech and voice analysis for assistance in diagnosing COVID-19 are expected to have great interest, since these are non-invasive and inexpensive [74]. Cases of intelligent speech analysis relevant for COVID-19 diagnosis among patients have been the focus of Han et al. [74] for developing potential, future use. Currently Han et al. [74] have already built audio-only based models from an analysis of patient speech recordings for automatic categorization of patient health states by four aspects: illness severity, sleep quality, fatigue and anxiety. Such experimentation by Han et al. [74] indicate a .69 percent average rate of accuracy relevant to the severity of illness, derived from the number of hospitalization days.

The class of CIoT that is specific for the medical industry is the Cognitive Internet of Medical Things (CIoMT). It holds a key position in smart healthcare. The availability of remote data on patients in real time to medical personnel include physiological data like body temperature, blood pressure, heart rate, glucose level, EEG, ECG, oxygen level and such as well as psychological data like speech, expression, and such. The IoMT delivers such data remotely [75]. Real-time communications of medical data are possible via Internet, and all hospital units caring for COVID-19 patients have extensive interconnections with Internet, making information transmittals both cost and time efficient. Real-time clinical parameters are available due to the assistance from CIoMT sensors, including the Electroencephalogram (EEG) sensor, Electrocardiogram (ECG) sensor, Blood pressure sensor, Pulse Oximeter, Electromyography (EMG) sensor and others. Such data is useful when assessing the severity an illness and when employing predictive analysis. Thereby, by monitoring feedback on patients, it becomes possible to prescribe effective treatments of the disease [76].

Next, the COVID-19 time series can be forecast a hybrid intelligent approach, as Castillo and Melin [77] explain, by a combination of fractal theory and fuzzy logic. The complexity of dynamics in the time series of countries around the world can be measured by the mathematical concept of fractal dimension. Castillo and Melin [77] provide a key contribution by proposing the hybrid approach, which combines the fractal dimension and fuzzy logic, that then facilitates fast and precise COVID-19 time series forecasting. Use of the information in a short window assists decision-makers in taking immediate actions needed in the fight against the pandemic according to this proposed approach. Meanwhile this same approach is also beneficial in the use of the longer window, such as the 30-day one, for long-term decisions, as per the study by Castillo and Melin (2020). Self-organizing maps were applied by Melin et al. [78] for their analysis of the spatial evolution of the global coronavirus pandemic. The clustering abilities of these self-organizing maps served as the basis in this Melin et al. [78] analysis to spatially group countries. Such groupings form in terms of similarities relevant to their coronavirus cases. These have enabled the use of similar strategies to benefit similarly behaving countries in managing the virus and curtailing its contagion.

The central objective for the study by Dansana et al. [79] was a classification of X-ray images in three categories — those of people ill with pneumonia, ill with COVID-19 and healthy people. The two algorithms used were convolution neural networks and decision tree classification. Dansana et al. [79] were able to infer highly satisfactory performances by the fine-tuned version of the VGG-19, Inception_V2 and decision tree model. These indicated a 91% rate of increase in training and validation accuracy compared to that of the Inception_V2 (78%) and the decision tree (60%) models.

Clinical trials applying marketable wearables for identifying and screening COVID-19 have been enacted recently by an entire array of universities like, e.g., Stanford University, Florida Atlantic University, McMaster University, Central Queensland University and University of California San Francisco; scientific research institutes like, e.g., Scripps Research Institute; hospitals like, e.g., Cleveland Clinic and companies like, e.g., AVA Sensors and NEC XON. These studies examined different physiological parameters of people like, e.g., temperature, heart and respiratory rates, heart rate variability, activity and sleep levels, oxygen saturation, sleep measures, galvanic skin response, electrodermal activity, electrocardiogram, blood pressure and others.

Some of the health metrics that consumer devices can measure quite easily include, e.g., respiration rate, heart rate and heart rate variability. These are notable for their ability to foresee early symptoms of potential illnesses. An additional feature is the ability of mobile applications accompanying wearable devices to gather data on related, self-reported symptoms and demographics. Such consumer devices can play valuable roles in the battle against the COVID-19 pandemic [80]. Two approaches for assessing COVID-19 were considered by Natarajan et al. (2020). These were a symptom-based approach and a physiological signs-based technique. Illness usually raises the respiration rate and heart rate; whereas, heart rate variability generally drops. An early diagnosis of this condition is possible by recording a history of such measurements. Such a history aids in tracking the progress of the illness as well [80]. The digital infrastructure for remote patient monitoring has come into prominence during the recent COVID-19 pandemic. The clear-cut need is for harnessing and leveraging it. Tests and related vaccines are implemented slowly, making clear the deficiencies in disease detection and in the monitoring of health at both the individual level and for the entire population. The assistance for accomplishing these tasks can come from wearable sensors. Numerous physiological parameters can be accurately measured remotely due to the developed, integrated sensor technology. Such measurements have proven beneficial for tracking the progress of a viral disease. This technology has a wide range of impact. For example, a person who is under quarantine at home may suddenly require better care, and this technology can be brought into play. Another example might involve an entire community under threat of an oncoming outbreak of illness that vitally needs immediate intervention [81].

Physiological metrics have been correlated with daily living and human performance pertinent to the functionality of this technology. Nonetheless, this technology must translate into predictions of COVID-19 cases. People wearing devices that are joined to predictive platforms could receive alerts regarding changes in their metrics whenever they correspond with possible COVID-19 symptoms. Depersonalized data gathered on the basis of neighborhoods or zip codes, especially during a second wave, could prove valuable for public health officials and researchers for tracing and alleviating the spread of this virus. Once certain persons are identified with a COVID-19 diagnosis, others with whom they have associated, such as families, coworkers and persons encountered in businesses and other facilities, can also be engaged into remote monitoring. Thereby very needed data regarding the speed of disease transmission and the beginning of its pertinent symptom manifestations can be detected [81].

3. Diurnal, seasonal and COVID-19 analysis multimodal biometric (CABER) method

Lately, one of the main worldwide topics of the motivation of COVID-19 research constitutes large-scale screening, diagnosis, monitoring, and categorization of people based on the presence of COVID-19 symptoms. The motivation and goals for having the willingness to conduct all such studies is to minimize or entirely eliminate the ongoing coronavirus pandemic. Motivation and objective have been upgraded for the present research under performance here by employing the Diurnal, Seasonal and COVID-19 Analysis Multimodal Biometric (CABER) Method. Its use is meant to establish people's emotions as well as their affective and physiological states with an objective to minimize bad moods during the COVID-19 period.

Theories, data, location and time

The Diurnal, Seasonal and COVID-19 Analysis Multimodal Biometric Method was developed during this research. This method measures and analyzes the human diurnal and seasonal rhythm correlations and patterns by biometrical techniques.

Mood stimulates the choices of activities (e.g. entertainment) to pursue, thereby providing quite a thorough explanation known as the Mood Management Theory [82]. An inherent assumption of this theory is that people are generally motivated towards pleasure, a state of a positive mood as well as an opposition towards negative states. The premise that is fundamental to mood management is that the motivations of people are to increase or retain pleasurable states and to reduce or eliminate painful states; therefore people will arrange their surroundings to accommodate such states. For example, media selection seem to contain two primary factors that associate with mood management. For one, consumers generate surroundings that will foster desirable levels of arousal, or a good mood, also associated with pleasure. The other is generating surroundings that will reduce or eliminate a painful, or bad mood [83].

Behavior and decision-making choices develop as a result of how emotions arise, which constitutes the essence of the Somatic marker hypothesis expounded by Damasio [51]. A brief explanation is that somatic markers denote the sorts of feelings, which emotions stimulate. Learning entails a connection of certain emotions and feelings, which can forecast the results of certain kinds of scenarios. An alarm sounds whenever a negative somatic marker associates with some specific future result. Meanwhile, incentive becomes aroused whenever the association involves a positive somatic marker [51].

Various diurnal and seasonal cultural activities influence happiness, valence and face temperature values. Additionally weather and climate affect human behavior to an important degree. Nevertheless, people always have an entire array of similar alternative choices, which they can select depending on their internal state of mind, needs, temperament, personality, surrounding environment, time of the year, weather (temperature, rain, humidity) and climatic conditions. For example, the length of the day and happiness correlate with the overall level of sunshine, its duration and air temperature, which, on their own accord, influence the priorities people set for themselves and the activities they choose.

This research investigates changes in levels of happiness, sadness and valence among depersonalized individuals on hourly, daily and seasonal bases, and measurements and recordings were taken in Vilnius in real time, between November 22, 2017 and May 20, 2020. An impact assessment regarding data protection for the Sensor Network was completed prior to beginning data gathering, as required by GDPR requirements and the applicable laws of the Republic of Lithuania. IP cameras and FaceReader 8 devices were set up to record data from anonymous passersby at seven corners of Vilnius city streets: Kareiviu St., Kalvariju St. and Ozo St.; Zygimantu

St. and T. Vrublevskio St.; Santariskiu St. and Baublio St.; Sventaragio St. and Pilies St.; Sventaragio St. and Gedimino Pr.; Pamenkalnio St., Jogailos St., Islandijos St. and Pylimo St.; and Sventaragio St., T. Vrublevskio St. and Gedimino Pr. A total of 180 million data items relating to emotions and valence were gathered from these seven sites. The values assigned to the emotional states (happy, sad, angry, scared and disgusted) ranged between zero and one, whereas the values of valence ranged between −1 and one.

The results of worldwide research [84-86] indicate that human skin temperature rises as positive or negative emotions rise. Homeostasis is a manifestation when the system retains a stable condition for itself. Even though hormones partly regulate homeostasis, it is the nervous system that ultimately regulates it. The nervous system returns some standard parameter such as temperature, which has deviated from its normal level. An argument promoted by Zillmann et al. [82] regarding mood involves the subconscious of people when they selects certain activities like media choices. The subconscious directs the retention of homeostasis (beings required to regulate body temperature, etc.) by normalizing arousal, which has been at an overly high state [84]. It acts to better states of negative moods [82, 83].

The FLIR A35SC infrared camera took 27,948,477 temperature measurements from depersonalized passersby between September 19, 2020 and November 2, 2020, in Vilnius, at the corner between Šventaragio St. and Pilies St.

A value, the date and time of collection and the location of the collected measurement identified every single item of collected data on happiness, sadness, valence and temperature. Local times were used in this study. FaceReader 8 was used to analyze the incidence of positive or negative valence for the emotions experienced by the passersby. There was one positive emotion (happy), and the remainder were negative (sad, angry, scared and disgusted). Valence was calculated by taking the intensity of "happiness" and subtracting the intensity of the strongest negative emotion [87]. In this way, we merged positive and negative emotions into a single value, known as valence.

No demographic data (such as gender, nationality, ethnicity, education, age, religion and socioeconomic status e.g. income, education and occupation) were gathered on the passersby in this study. This research involved innovative experiments with primary, remotely accumulated, biometric data, and testing was conducted on a large scale in order to examine collective emotions. This study therefore extends existing research involving daily and seasonal biometric studies of collective emotions, to the best of our knowledge, since it covers a much more varied range of socioeconomic and demographic groupings.

Assessing the accuracy of data and results through verification and validation

All the accumulated data were validated and verified in a double-checking process.

Two objective datasets of basic human emotions, both of which are available to the public, served as the basis for validation of FaceReader, performed by Lewinski et al. [88]. These authors also assessed the accuracy of facial expression recognition. There were scores reported to FaceReader of which 89% were matching in 2005. FaceReader 6.0 was shown to be capable of distinguishing 88% of the target emotional labels from the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP) and the Amsterdam Dynamic Facial Expression Set (ADFES). Then, there is the agreement index pertinent to the Facial Action Coding System (FACS). It achieved an average score of 0.69 for both datasets, which indicates an 85% rate for the recognition of human emotions. The first two datasets were also examined by Lewinski et al. [88], who calculated an 87% accuracy of recognition of human emotions for ADFES and an 82% rate for WSEFEP. The authors of

these studies claim that over the past decade, FaceReader has been proven to be a reliable indicator of basic human emotions based on facial expressions. They also assert that it can be similarly reliable when used with FACS coding. Researchers report an 88% accuracy for the recognition of basic emotions by FaceReader 6.0. The FaceReader agreement index accuracy for FACS is 0.69 [88]. Other scholars have obtained similar results in tests of the validity of FaceReader and its accuracy, and their outlooks on Noldus Information Technology, the producer of this equipment, tend to be similar.

FaceReader 8.0 software has been applied for writing this article on an artificial intelligence technique regarding machine learning. This FaceReader 8.0 software for an artificial intelligence technique in machine learning has also been applied in other studies, which are further briefly presented. The validation of automated facial coding (AFC) by FaceReader artificial intelligence software was presented by Lewinski et al. [88]. Another study relevant to consumer preferences of beverages, which was conducted by Gonzalez Viejo et al. [89], applied artificial intelligence as the basis for analyzing emerging technologies for the purpose of quality assessments. This same FaceReader software had been used by Viejo et al. [89] for assessing food and beverages. It involved recognizing facial expressions to study their relationships to emotions. An interesting combination of robotics and computer vision techniques with non-invasive consumer biometrics appears in the study by Viejo et al. [89]. These biometrics consist of FaceReader™ 7.0 software, an infrared thermal camera and an eye tracking device. This study also involves a sensory questionnaire, which used machine learning for evaluating different features of beer foamability. Viejo et al. [89] hold the view that their study shows potential opportunities for applying artificial intelligence (AI) by using robotics, computer vision and machine learning algorithms. These then perform quick screenings of carbonated brewages.

The accuracy of the infrared camera FLIR A35SC was 2% (FLIR), while its thermal sensitivity was 0.05 °C. A calibration certificate issued by the manufacturer of this camera confirms all pertinent calculations and measurements. Annual metrological verifications are also issued for thermographic cameras to ensure that the error rate pertinent to the manufacturer-set measurements does not deviate. The thermal data transferred are processed as part of the data validation, thus ensuring high quality in terms of accuracy, update status, completeness, consistency across data sources, relevance, reliability, appropriate presentation, meaningfulness and accessibility. The processing also double-checks the accuracy and suitability of the data. Such a step in data processing has uncovered inaccuracies in some of the data, thereby assuring immediate next steps to resolve the problems. Data can also be deleted whenever problems prove insurmountable, and, thereby, inaccurate, incomplete, rounded off, heaped, censored and/or missing data then cease to be problematic. An analysis of average facial temperature involved a selected range that was segmented using thermal imaging. However, this sort of measurement is only applicable to the average facial temperature of a crowd, and temperature values that could distort the results of the study were deemed unnecessary and eliminated. At the data processing stage, we also eliminated the average temperatures of people in the background, that is, outside the observation zone [90].

4. ROCK and housing COVID-19 video neuroanalytics

The H2020 ROCK project conducted in Vilnius city during which the ROCK Video Neuroanalytics and related infrastructure were developed involved studies of passers-by at eight sites in the city [90]. We analyzed the Vilnius Happiness Index (see https://api.vilnius.lt/happiness-index) with ROCK Video Neuroanalytics in real-time, also conducted different other activities (see

https://Vilnius.lt/en/category/rock-project/). The ROCK Video Neuroanalytics consists of framework containing a Database Management Dystem, a Database, Sensor Network, a Model Database Management System, a Model Database and a User Interface. The kinds of states stored in the ROCK Video Neuroanalytics Database are emotional states (happy, sad, angry, surprised, scared, disgusted or a neutral state), affective states (boredom, interest and confusion) and physiological states (average crowd facial temperature, crowd composition by gender and age groups as well as heart and breathing rates), arousal and valence. These are the MAPS data assembled in the Sensor Network. The subsystems contained within the Model Database are the Data Mining Subsystem, Recommendations Model, Decision Support and Expert Subsystem and Correlation Subsystem. Meanwhile the Database consists of the developed Video Neuroanalytics as well as the Historical, Recommendations, Decision Support and Expert Subsystem Databases. Remote data generated from affective, emotional and physiological parameter measurement devices base the compilation of a Sensor Network. Such remote data consist of MAPS data, sex, age (as per FaceReader 8), temperature (as per Infrared Camera FLIR A35SC), breathing rate (as per Sensor X4M200) and numbers of passersby (as per the H.264 Indoor Mini Dome IP Camera).

A study pertinent to elderly age by Speth et al. [91] discovered baseline depressive mood and anxiety levels during the pre-COVID-19 period, which positively associated with more depressive moods and anxiety during the COVID-19 period. Headaches, stress, stroke, itch, cerebrovascular dysfunction and BBB disruption are all examples of COVID-19-caused symptoms stemming from numerous neurological problems [92]. A study involving 239 patients of which 133 were males and 106 were females, all with COVID-19 diagnoses, was performed by Karadaş et al. [93]. Of the 239 patients, 83, or 34.7% involved neurological findings. COVID-19 causes harm to the nerve and muscle systems. Typical neurological symptoms include headache, muscle pain, sleep disorder, impaired consciousness, smell and taste impairments, dizziness and cerebrovascular diseases [93].

Then, in 2020, a study was conducted by Nalleballe et al. [94] on 40,469 COVID-19 positive patients. Its finding was that 22.5% of patients displayed neuropsychiatric symptoms associated with COVID-19. A handful of minor studies corresponded with this same finding. These had been performed by Mao et al. [95] and Helms et al. [96]. There appears to be a potentially strong relationship between coronavirus infections and psychosis. COVID-19 patients display neuropsychiatric symptoms, which customarily include anxiety, mood disorders, headache, sleep disorders, encephalopathy, stroke, seizures and neuromuscular complications [94]. Neuropsychiatric symptoms appear from the start of a COVID-19 illness whether it is mild, moderate or severe. The kinds of neuropsychiatric symptoms include anxiety, panic attacks, depression, mental confusion, acute confusional syndrome, psychomotor excitement, psychosis and, possibly, suicidal inclinations. The importance of these symptoms appearing in COVID-19 cases is that patients suffer these in addition to the customary symptoms of fever, cough and dyspnea. The suffering of such an illness further causes apathy, anorexia and muscular pain [97].

Morbidity and mortality have outcropped significantly during the ongoing COVID-19 pandemic due to neurological complications. A large number of hospitalized patients indicate neurological symptoms in addition to a respiratory insufficiency. Such symptoms appear as a wide range of maladies from a headache and loss of smell, to confusion and disabling strokes [98]. Coronavirus-caused neurological maladies constitute clear-cut pathogenic symptoms. The damage caused by neurological impairments can extend from general, cognitive and motor dysfunctions up to a wide spectrum of CNS anomalies like anxiety and other kinds of audio-visual incapacities [99].

The Housing COVID-19 Video Neuroanalytics will be developed over the course of implementing the MICROBE Project by adapting the ROCK Video Neuroanalytics for a potential analysis of negative emotions and the coronavirus. The Housing COVID-19 Video Neuroanalytics framework consists of

the ROCK Video Neuroanalytics and e-Questionnaire COVID-19 Symptom Surveys, e.g., see https://covid-19.ontario.ca/self-assessment/ and https://www.mayoclinic.org/covid-19-self-assessment-tool. It additionally contains a Correlation Subsystem and a COVID-19 Subsystem and User Interface. The Correlation Subsystem is capable of analyzing different correlations relevant to the MAPS metrics on the diurnal, seasonal and coronavirus lockdown along with their impact on people. Meanwhile users can manage the Housing COVID-19 Video Neuroanalytics by the convenience of the provisions from the User Interface.

Also, the developed Housing COVID-19 Video Neuroanalytics will include specific measurements from wearable devices and the COVID-19 Subsystem. Further, there is brief mention of some wearable measurement devices, which collect different physiological data like heart rhythm in a peaceful state and its variability, fatigue, bodily pain, taste and smell, cough, fever and pf activity rate. The expectation is to integrate all of these into the Housing COVID-19 Video Neuroanalytics. Currently wrist monitors predominate in the market. Such monitors include WHOOP, Apple Watch Series 4/5, Chest Patch sensor, Garmin Vivoactive 4, Garmin Forerunner 945, Garmin Fenix 5, Garmin Venu, Biostrap, Empatica Embrace, Fitbit Ionic, Fitbit Charge 4, Fitbit Versa 2 and Biobeat devices. The other monitoring devices under analysis at this time include those made by the following companies: the Oura ring, VivaLNK Vital Scout and VivaLNK Fever Scout epidermal patches, BioIntellisense epidermal patch, Spire health tag that attaches to clothing, Hexoskin compression shirt, Biovotion Everion armband, Equivital LifeMonitor chest strap, Cosinuss Two in-ear device, AIO Sleeve 2.0 arm. The prices for such monitoring devices range from $30 to $500 USD. Global practice indicates that the integration of multidimensional biometrics and measurements show greater value for their predictive abilities.

The Housing COVID-19 Video Neuroanalytics will include possible monitoring COVID-19 infected by analyzing them in practical scenarios such as universities, housing, and a neighborhood under the threat of an oncoming outbreak of illness that vitally needs immediate intervention.

The COVID-19 Subsystem can trace symptoms relevant to a COVID-19 infection in the future, which collects a human body's heart and breathing rates, temperature and other physiological (heart rhythm in a peaceful state and the variability of heart rhythm, fatigue, bodily pain, taste and smell, cough, fever, rate pf activity) data. This data is then joined with the responses gathered from the surveys of daily symptoms, thus predicting the possible onset of the illness. An upsurge in temperature and other physiological data can denote a potential COVID-19 infection in a person, whenever data from the e-Questionnaire COVID-19 Symptom Surveys combined with data from the Sensor Network so indicate.

5. COVID-19 and Green Housing

The current health emergency has proven to be a crisis like none other recalled in modern times. There seemed to be no other manner to overcome it, but for countries to instigate lockdowns that brought their economies to a standstill. Thereby the result has been the worst recession since the Great Depression. Lives were overturned in numerous ways to deal with this crisis. The ensuing collapse of economies occurred at unimaginably rapid rates and magnitudes. Changes to people's lives everywhere have been profound: slowdowns of economies, loss of jobs, upheavals of climates, upsurge of technology and automation resulting in job losses, upswing of digital currencies, depressed returns on savings, greater inequalities and rising debts. Nonetheless, along with the usual global forces, this unexpected crisis holds promise of a new challenge and opportunity at building a brighter tomorrow for everyone. Good faith and shared goals constitute the means for

solutions even when the problems are unusually pressing. The expected recovery then can mean a global economy that serves all [100].

The housing sector has suffered numerous difficulties from the pandemic, including in the field of green buildings. The sector's problems are not limited to the present but will continue for some time. Problems include renting during the COVID-19 surge. Responses to pandemic policies require attention, and these need to be understood in terms of their impacts. Other topics involve coordinating policies in light of housing outcomes during the COVID-19 outbreak. Then, following the pandemic, consideration must be made of relationships between landlords and renters and of the entire concept of green buildings. Lockdowns have already lasted over 10 months. Thus people were forced to sleep, eat, work, work-out and socialize, all at home. This leads to one conclusion – larger living spaces that overlook green areas need to constitute the focus of green housing design strategies.

The COVID-19 pandemic has added a great deal of uncertainty to many areas of human life—at work, at home, in leisure time. For many people their homes are now the only place where they work and spend free time. A look at various aspects of housing through the lens of the pandemic is, therefore, very important. The question is whether the drive to protect human health will become the key point in the analysis of housing priorities, with a focus on the quality of indoor environment, the choice of building materials, and expected changes in sustainable design requirements for residential buildings. Finally, a rethinking of sustainability requirements for residential buildings is one challenge of this pandemic. Future building assessment will likely focus more on its occupants than the building itself. More waves of the COVID-19 outbreak are possible and to mitigate its influence, its impacts must be analysed.

Currently many countries face many challenges and needs for housing improvements requiring solutions. Micro-, mezzo- and macro-environments in housing pertinent to COVID-19 involve numerous aspects. Working from home is on an upswing; thus suitable environments must be enabled. COVID-19 is bound to cause new requirements for future homes. These will involve resource efficiency throughout a building's lifecycle, larger lots as well as smart bathrooms and bidets. There will be new aspects to multi-generational homes, which will now require unique spaces, such as, e.g., more rooms and more bathrooms. Future homes cannot be simply smart homes — they must be healthy and energy-efficient homes. Floor plans will require more open spaces. Creative locales within the home can be designed for office use. Management teams will be designated for infrastructural facilities and different, smaller teams for technical facilities. Daily hygienic needs must be on-site in simplified designs. Checklists must be generated for daily health and safety needs. BIM and other digital means need to fight with COVID 19, e.g., by digital risk monitoring on construction sites and in work sites. Relevant systems would include data analysis, alerting, video surveillance, IoT and non-invasive temperature monitoring. Plans should include reporting on health on a daily basis and the ability to diagnose remotely. Proptech would change facilities management on a step-by-step basis by employing workplace wellbeing, efficient energy consumption, optimal use of available space and data management.

The literature under review originated only in part of the countries the pandemic has affected. Therefore the studies reviewed do not include all the areas around the world that have been infected by this virus. Hence the affected countries with extremely vulnerable populations still call for adequate coverage. Nonetheless, there is a considerable overview of proposed policies aimed at the pandemic, so the green housing research community and its overall sector has been considered in light of the main, pertinent guidelines.

Aspects of green housing in the era during and post COVID-19, green housing trends and its interrelations are presented in the Figure 1. These factors are briefly analyzed below.

A quantitative analysis on green housing is possible by applying the Topic Model, Environmental Psychology Theory, building life cycle method and certain elements of Bibliometrics, Webometrics, Article Level Metrics, Altmetrics and Scientometrics. These methods are briefly described next.

"How can the development of ideas in a scientific field be studied over time?" This was the question that Hall et al. [101] attempted to answer by studying the history of ideas using topic models. An analysis of the historical developments in Computational Linguistics field from 1978 to 2006 was also undertaken by Hall et al. [101] by applying unsupervised topic modelling to the ACL Anthology. Their study involved inducing topic clusters by applying Latent Dirichlet Allocation for investigating the strength of every topic over time. The methods employed by Hall et al. [101] discover developments in this field. These included the rise of probabilistic methods from their beginning in 1988, a stable growth of pertinent applications and a pronounced drop of research in semantics and understanding between 1978 and 2001, which showed some growth only after 2001.

Rosen-Zvi et al. [102] provide the author-topic model for modelling topics pertinent to document authors, meant to upgrade topic detection in documents with authorship information. Topic modelling on abstracts from the PNAS Journal was applied by Griffiths and Steyvers [103] to identify topics with growing or falling popularity from 1991 to 2001. A topic model for geographically distributed documents was developed by Yin et al. 2011) [104]. Here latent regions detected by inference, which explain document positions. Newman and Block [105] determined the temporal dynamics of topics from 1728–1800 in the Pennsylvania Gazette, which constituted an approach for temporal information. Network information between linked documents in the relational topic model were included by Chang et al [106] for the purpose of modelling such links between websites. Meanwhile Lamba and Madhusushan (2019) [107] were applying topic modelling on full-text research articles that they took from the DJLIT Journal from 1981–2018.

Webometrics is the term Almind and Ingwersen [9] applied to reference quantitative studies of the web. A definition of webometrics was provided by Björneborn and Ingwersen [108]. They claimed it is the study of bibliometric and informetric approaches, which serve as a source for the quantitative aspects of the construction and use of information resources, structures and technologies on the Web.

Bibliometrics refers to the analysis of scientific publications by applying a set of quantitative methods. A bibliometric study involves quantifiable forms of a publication or any aspect of that publication, such as its number of words, the time delayed after its submission until its publication and other similar aspects. Bibliometric measures that appear most often are the following [109]:

- The productivity of some certain researcher or research group measured by the number of respective publications issued.
- The number of citations from a publication appearing in later publications written by other scholars to indicate the interest generated by that respective publication.
- The number of downloads of an electronically available publication by readers to indicate its importance.
- The number of times on average that articles published in certain journals are cited within a certain time period following publication to indicate of the scientific importance of that journal or how comprehensive its peer review is.

How the scientific community handles a particular piece of research constitutes its scientific impact. Thus the interest the scientific community pays to some certain article in a professional journal after publication is a matter undertaken by Article Level Metrics (ALMs) by a wide range of metrics. Such metrics can include citations, usage statistics, discussions regarding online comments and social media and social bookmarking as well as different recommendations [110]. Lin and Fenner [110] covers why Article Level Metrics constitute an important extension of traditional

citation-based journal metrics as well as presents several examples. A variety of metrics, e.g., have been accumulated and displayed by PLOS since 2009 for every one of its articles. Furthermore PLOS also collects metrics about how many times an article has been saved in online reference managers like Mendeley in addition to its statistics on the frequency a certain article has been viewed and downloaded, meaning the statistics on its citations and usage. Other metrics included by PLOS regard the frequency of discussions about an article in its online comments, in science blogs and/or in the social media. In addition to these metrics, PLOS also notes the frequency of recommendations of a certain article by other scholars. A consideration of citations alone would exclude all the other valuable information, which these added metrics provide [110].

The "impact" or "reach" of some, one article is referenced as Article Level Metrics (ALMs), referencing an entire range of measures offering such insights. Citations at the journal level are measured by the well-known Impact Factor. Meanwhile the research impact of an article is measured by ALMs aiming for transparency and thoroughness. ALMs view citations and their usage and, additionally, present the coverage of an article along with discussions that appear on the social web [111]. The discussions regarding an individual article along with its sharing and use comprise a picture that Article Level Metrics (ALMs) present. The effort of ALMs involves measuring impact at the level of a single article. To accomplish such a measure, some traditional data sources like times cited are used by ALMs as well as certain new sources like tweets. The definition of altmetrics specifically references such an effort to include new data sources for measuring impact brought about by either an article, a journal or even by some certain scholar. Data sources are the heart of altmetrics, not some level of aggregation. ALMs specifically define the impact of some, certain article by merging altmetrics with traditional data points [112].

A different group of metrics has appeared recently, over the past few years. This group, which has evolved to becoming a topic of interest and research in scientometrics, is now known as alternative metrics or altmetrics. It obviously differs from classical bibliometrics, as its name indicates, since it offers an alternative to citation analysis [113]. In Lin and Fenner [110] opinion, altmetrics used a very wide-ranging collection of metrics, such as citation of papers, papers views and downloads, recommended, science blogs, journal comments, discussed in Twitter, Wikipedia, Facebook. Altmetrics is especially well defined by Priem et al. [114], who describe what it involves and how it can be used in addition to pinpointing the subjects of its focus. That different alternative metrics could be correlated with numerous traditional metrics, including, e.g., citations, was proposed by Priem et al. [114], or, alternatively, expert opinions might undertake an analysis of such a correlation.

The scientific measurement of work of scholars involving the means of analysis of their publications along with the citations within those articles is known as scientometrics (Wiktionary). The measure and analysis of science is a science called Scientometrics. Its practice frequently involves the use of bibliometrics or measuring the impact of publications (Freebase). Scientometrics is an instrument of the Sociology of Science, which is a sub-discipline dealing with quantitative evaluations of scientific activity that documents the sectoral economy of the scientific optical discipline, as per Vega-Muñoz and Arjona-Fuentes [115]. Furthermore these scholars proclaim that its application can also extend to the sub-discipline covering the sector of economics research and development.

In order to design and implement an effective green building life cycle process, it is necessary to analyze comprehensively its constituent parts, the participating in it interested groups as well as to consider external micro- and macro environment impact. In green building life cycle process stages, alternative variants are formed by changing a construction site, by varating possible green building volumetric-planned and other solutions, construction and maintenance processes, etc.

Variability of solutions helps to consider more rationally the present COVID-19 situation, external micro- and macro environment level factors, to make the project cheaper; to satisfy better architectural, aesthetic, comfort and other requirements of the client as well as aims of all participating in the project interested groups (see Figure 1).

How can effective green building life cycle process be determined, if different interested groups participate in it, there can be hundreds of thousands of alternative projects variants, when, with the change of constituent parts of green building life cycle process, COVID-19 situation, external environment, the effectiveness of the entire project also changes? Besides, the implementation of some aims can be more rational economically than others, however, they are differently significant from other aspects. Thus, it is considered that the effectiveness of green building life cycle process depends on the rationality of its constituent parts, the level of interested groups goals achievement and the rationality of the external environment. This analysis formally describes, how with the change of constituent parts of the project, COVID-19 situation, external environment, the level of different goals achievement, the level and price of green building life cycle process effectiveness change.

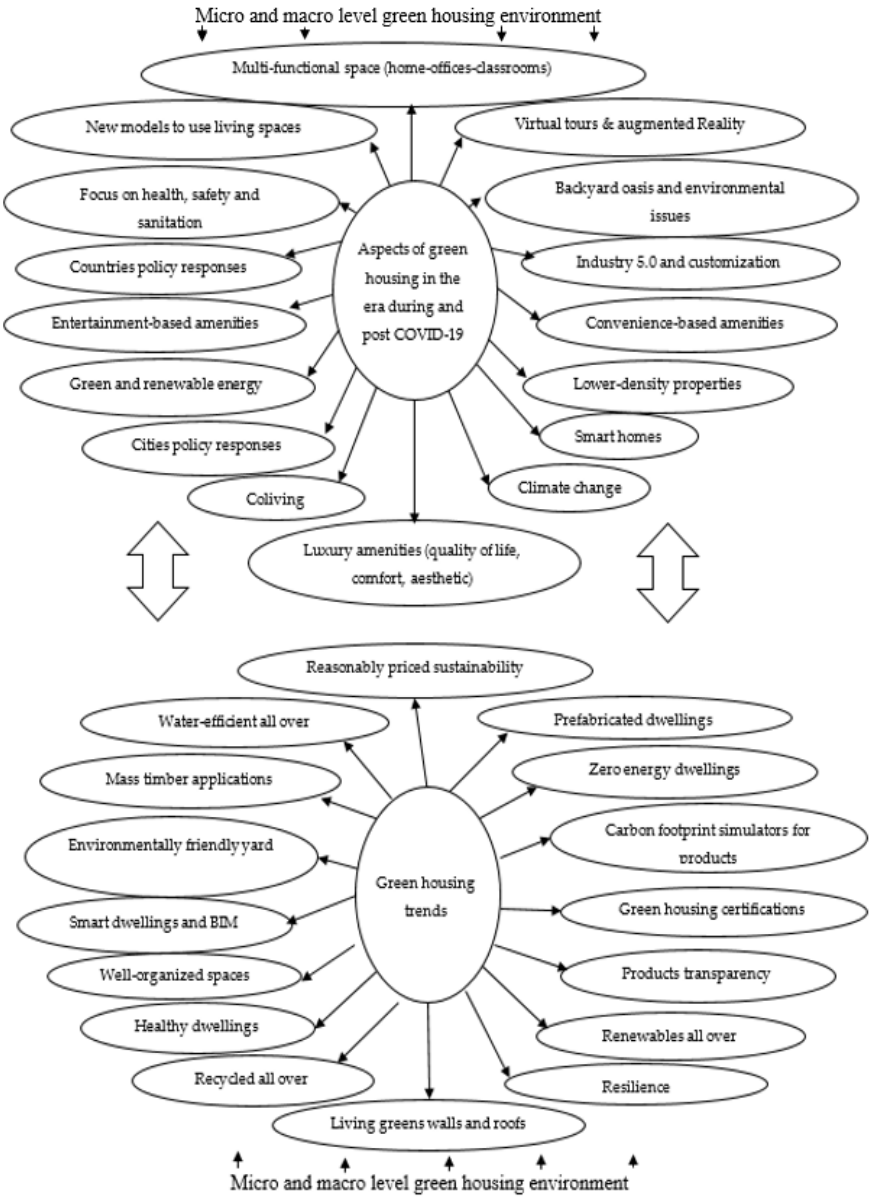


Figure 1. Green housing quantitative and qualitative aspects during and after the COVID-19 pandemic

5.1. Methodology

An integrated quantitative analysis on green housing before, during and after COVID-19 is possible by applying the Topic Model, Environmental Psychology Theory, building life cycle method and certain elements of Bibliometrics, Webometrics, Article Level Metrics, Altmetrics and Scientometrics. These methods were described in brief in the Introduction.

Development of the Green Housing Topic Model took place during the course of the research when the worldwide scientific literature was under analysis and the statistical analysis was taking place of appropriate articles from different bibliographic databases. The development of the Green Housing Topic Model occurred in seven stages:

1. Search
2. Compilation of a two-dimensional green building map
3. Comparison of articles published in 2019 and 2020 on green buildings by specific key search words
4. Raising a hypothesis (Hypothesis 1) on the correlation and distribution of topic words
5. Compilation of a colored document-frequency matrix
6. Raising and validating the two hypotheses (Hypotheses 2 and 3) and the interlink between them
7. Establishment of green housing trends on a micro and macro scope

Brief descriptions of these stages follow.

In the first stage of the Model, we performed a scientific literature search SCOPUS and Web of Science databases. We also analyzed the publications of American Planning Association and American Society of Civil Engineers peer-reviewed journals and the announced publications of Organisation for Economic Co-operation and Development. Databases were searched by using a combination of various keywords and the criteria for paper selection including green building, sustainable building, green construction, re-source-efficient, a building's lifecycle, COVID-19, energy, water, consumption, health effects, comfort, occupant behaviours, policy, economy, Industry 5.0, energy-efficient retrofitting and profit. Searches were limited to research published from 1974 up to the date of the search (5 March 2021).

For example, 3477 green building articles were publicized in a Web of Science Core Collection database from 1999 till 2021. The following papers were announced in Web of Science Categories: construction building technology (952), engineering civil (776), environmental sciences (607), architecture (311), environmental studies (298), urban studies (167), regional urban planning (111), public environmental occupational health (63), business (57), computer science artificial intelligence (57), etc. Web of Science Core Collection database green building Hi=81, average citations per item is 10.33, the sum of times cited is 35906 (without self-citations - 27692), citing articles are 21089 (without self-citations - 19600). In the analyzed period, in total 1877 articles, 1384 proceedings papers, 162 reviews, 41 editorial material, etc. were printed on green building topic.

Figure 2 displays a two-dimensional green building map. Its basis constitutes the data from the search SCOPUS database from the second stage of the model. This figure indicates topic similarities as per the manner of their distribution over keywords. The topic label additionally indicates how to best capture the semantics of the top keywords. Figure 2 presents the keywords taken from the search on green buildings in 2019 in a circle. These reflect the following on a green building:

- a life cycle along with the latest information, artificial intelligence and other technologies applied to it (top left)
- level of user satisfaction with green buildings and resources and aspects of green matters, environmental protectors and renewables (top right)

- national, city wide, residential area and decision-making dimensions (lower left)
- green building aspects (lower right)

Figure 2 submits circles in sizes indicative of the number of articles issued in ScienceDirect journals in 2019 according to the key search words for specific green buildings.

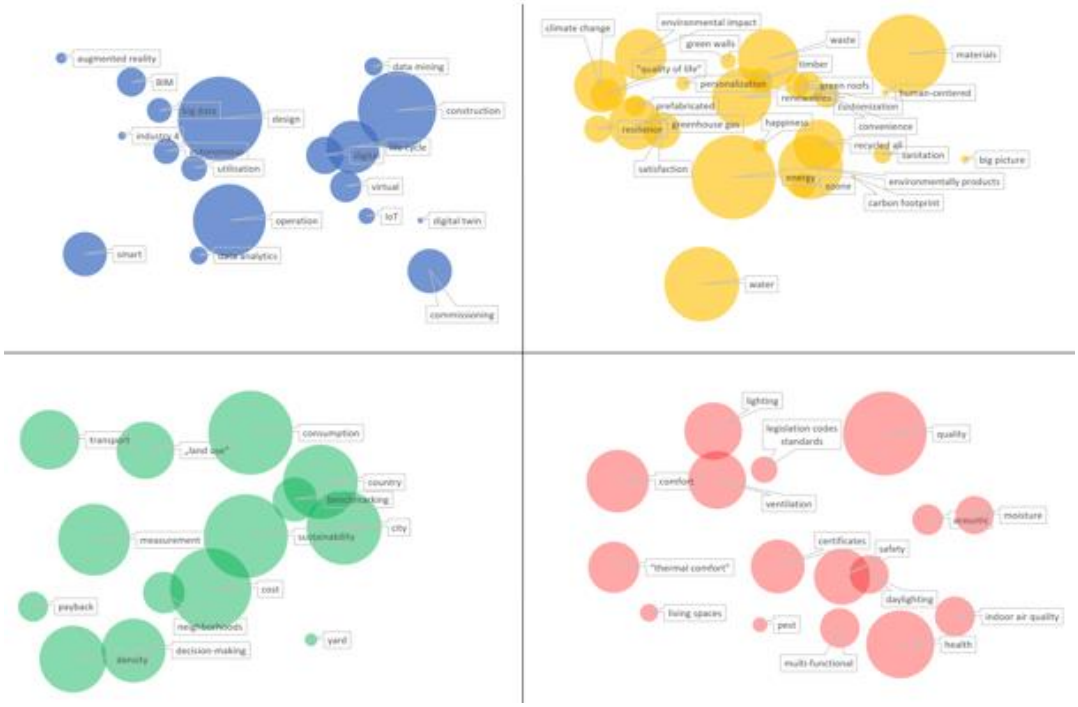
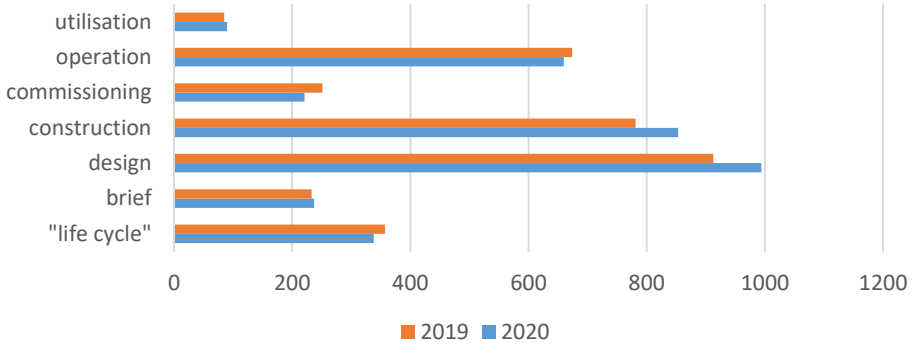


Figure 2. Two-dimensional green building map with circles in sizes indicative of the number of articles published in the Scopus journal database in 2019 according to specific key search words on green buildings

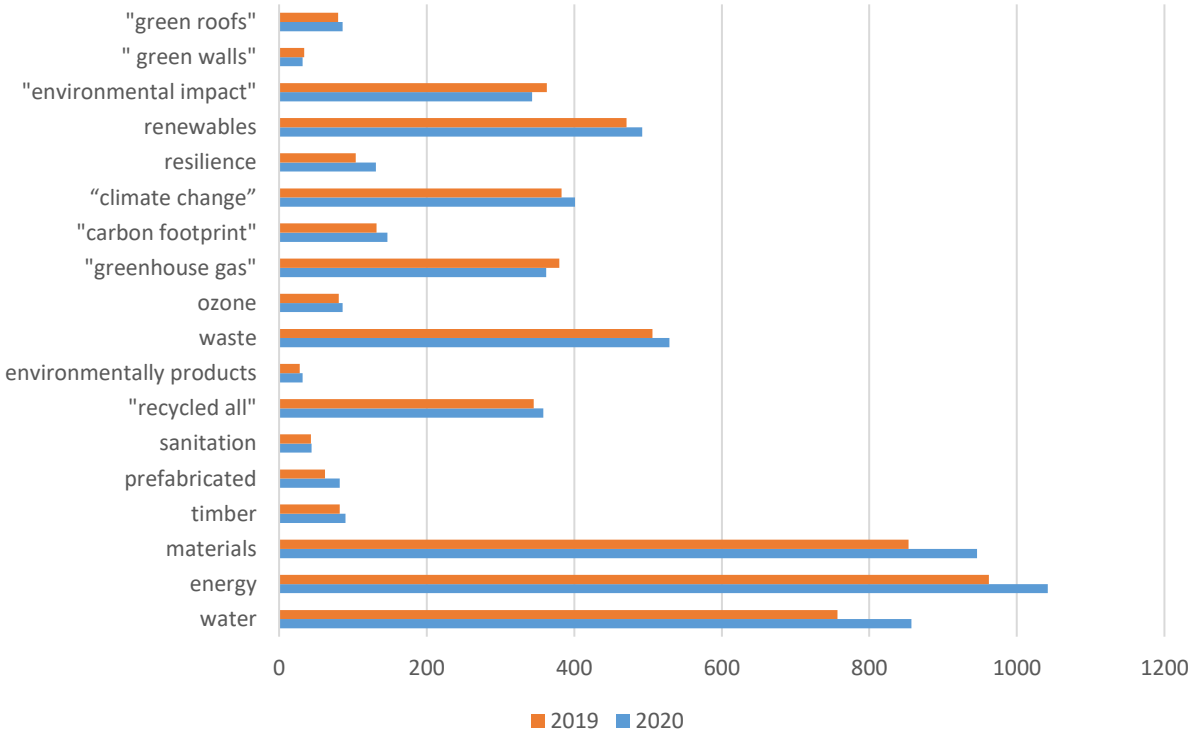
Comparisons of articles published in 2019 and 2020 in the Scopus journal database according to specific key search words for green building during the Third stage of the model. Figure 3 shows the y axis containing the numbers of articles found in the Scopus journal database by year according to specific key words. For example, in 2020, there were 853 articles in the Scopus journal database published according to the key words “green building” and “construction”, whereas, in 2019, there were 781 such articles. The overall number of articles in the 2020 database under analysis increased by 8.5 percent when compared with the 2019 database. Meanwhile, during this same period, the number of articles on green housing increased by 10.5 percent.

The correlation and distributional hypothesis of topic words was raised and substantiated during the Fourth stage. A qualitative approach to automatically uncover the coherence of a topic are, as proposed by researchers in the field, topic coherence measures [116], [117]. Meanwhile the root of the underlying idea lies in the distributional hypothesis of linguistics [118]. Additionally words with similar meanings tend to occur in similar contexts. Whenever all or most words relate with one another, e.g., the leading N words of a topic, then the topics are considered coherent [105]. The distributional hypothesis was also raised during the course of this research that the key words relevant to the green building topic strongly correlate with one another (see Table 1).

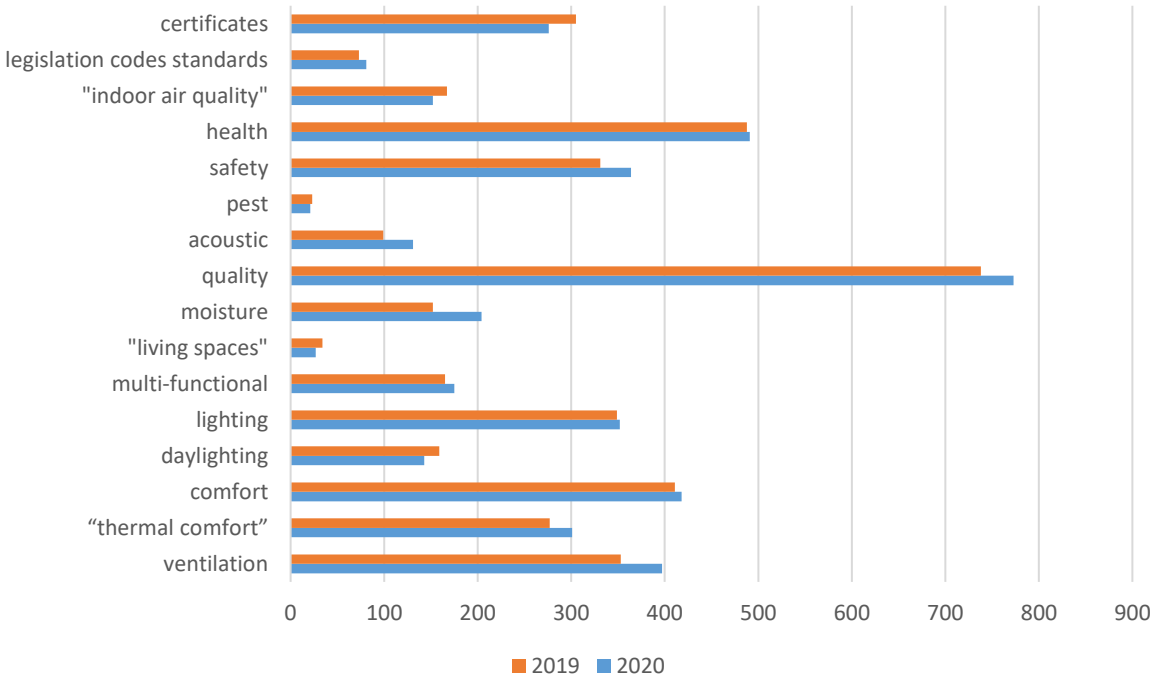
a) Green building life cycle



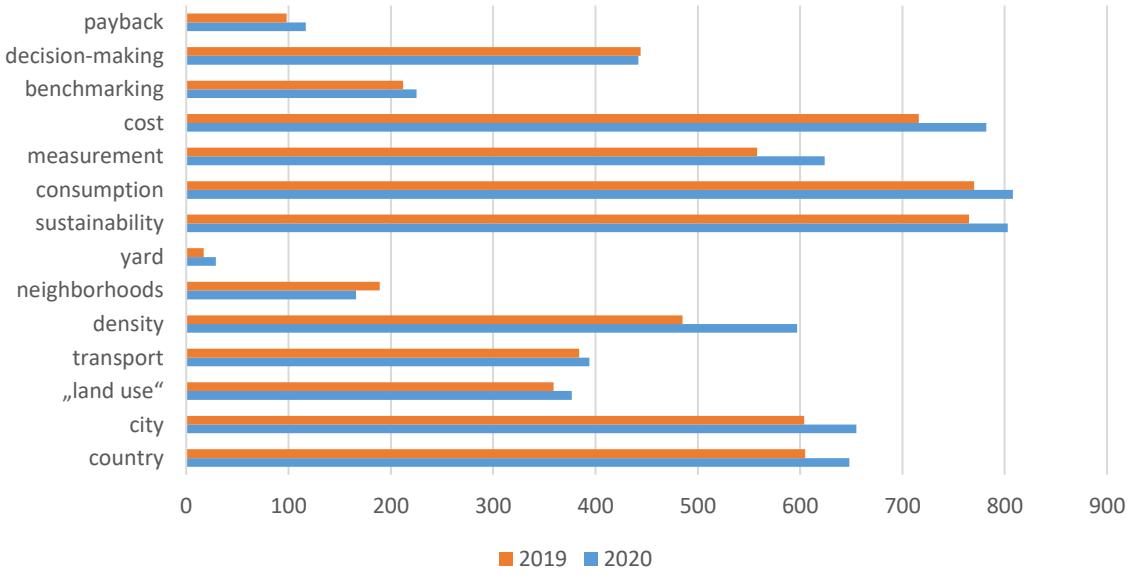
b) Resources, green matters, environmental protectors, renewables and climate change aspects



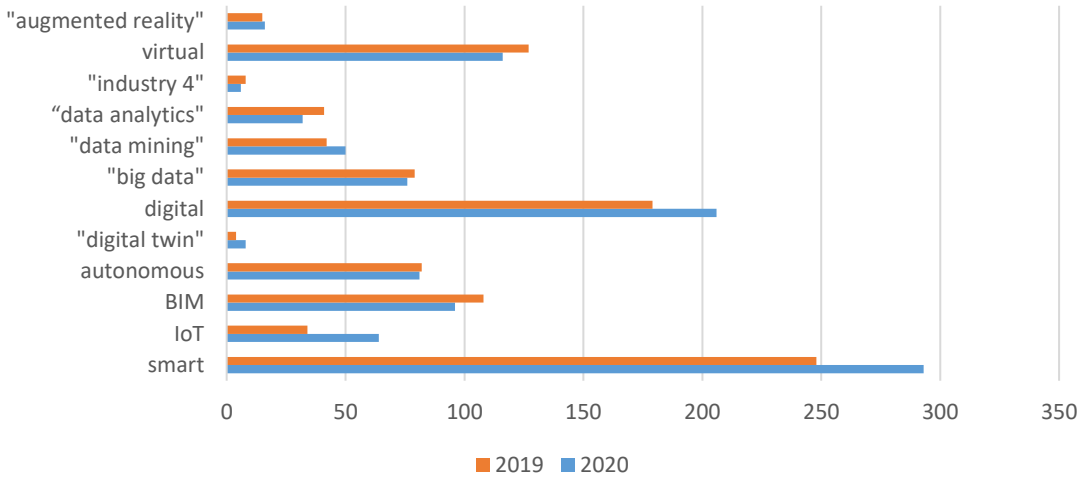
c) Green building aspects



d) National, city-wide, residential area and decision-making dimensions



e) Applications of latest information, artificial intelligence and other technologies



f) Level of user satisfaction with green buildings

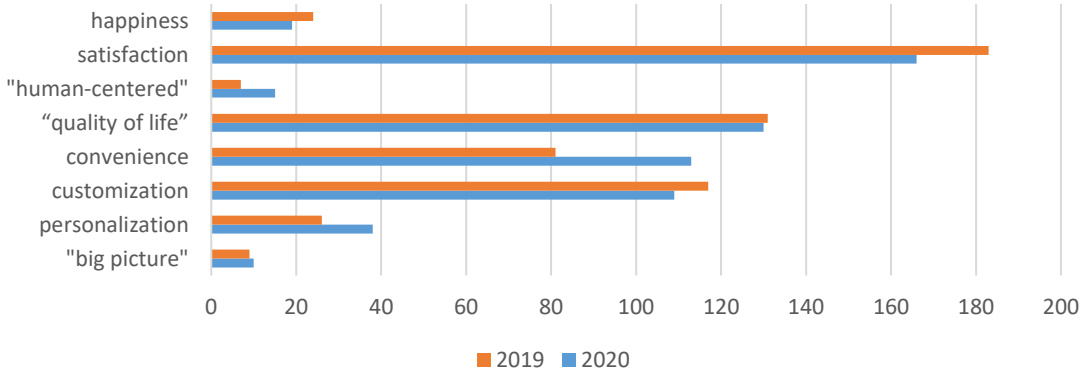


Figure 3. Comparison of articles published in the 2019 and 2020 Scopus journal databases by key words reflecting a) Green building life cycle, b) Resources, green matters, environmental protectors, renewables and climate change aspects, c) Green building aspects, d) National, city-wide, residential area and decision-making dimensions, e) Applications of latest information, artificial intelligence and other technologies and f) Level of user satisfaction with green buildings.

Table 1 shows a matrix in which the obtained correlation coefficients were strong between user satisfaction with green buildings, the life cycle of a green building and the national, city-wide, residential area and decision-making dimensions (see Table 1). Analogically strong correlations were also obtained between other key search words. These strong correlations indicate that the key search words were appropriately selected for performing the analysis on green housing before, during and after the COVID-19 Big Picture analysis. The distributional hypothesis was also confirmed during the progression of this study that the key words pertinent to the green building topic strongly correlate with one another.

The Fifth stage involves compiling a colored, document- frequency matrix. The columns of the colored, document- frequency matrix presented in Table 2 contain key words reflecting user satisfaction with green buildings and the life cycle of a green building. The rows of Table 2 contain the number of articles found in the Scopus journal database by year according to specific key words. For example, in 2020, there were 130 articles published in the Scopus journal database containing

the key words “green building” and “quality of life”, whereas, in 2009, there were 24 such articles. These numbers appear within the colored cells of the matrix by which the darkness of the color demonstrates the number of published articles, the darker the color, the greater the number of published articles.

The interlink between green housing and COVID-19 was methodically studied during the Sixth stage of the model to test the hypothesis regarding the interactions between COVID-19, the housing COVID-19 policies of relevant countries and cities and the behaviors of their residents along with their demands for green housing. Two hypotheses were raised during the Sixth stage:

- Hypothesis 2: COVID-19, housing policies of countries and cities during COVID-19 impact green housing and the wellbeing of their residents; additionally the residents and a housing policy impact the dispersion of COVID-19.
- Hypothesis 3: A green building analysis is markedly more effective, when the life process of a green building along with the interest groups participating in it with goals they wish to implement of their own, the COVID-19 situation and the external micro- and macro-level environments are comprehensively analyzed as a single entity.

Table 1. Strong correlation coefficients obtained between user satisfaction with green buildings, the life cycle of a green building and the national, city-wide, residential area and decision-making dimensions.

	country	city	"land use"	sustainability	"quality of life"	"human centered"	satisfaction	happiness	"life cycle"	brief	design	transport	density	neighborhoods	yard
country	1	0,995	0,995	0,996	0,992	0,776	0,991	0,853	0,989	0,994	0,997	0,997	0,991	0,987	0,899
city		1	0,995	0,995	0,989	0,774	0,984	0,856	0,980	0,988	0,996	0,997	0,994	0,986	0,880
"land use"			1	0,996	0,991	0,777	0,983	0,833	0,986	0,987	0,994	0,996	0,984	0,988	0,902
sustainability				1	0,985	0,726	0,986	0,827	0,993	0,987	0,998	0,995	0,986	0,984	0,900
"quality of life"					1	0,781	0,979	0,871	0,972	0,988	0,984	0,989	0,980	0,986	0,888
"human centered"						1	0,759	0,710	0,694	0,790	0,751	0,778	0,823	0,749	0,618
satisfaction							1	0,866	0,990	0,993	0,990	0,992	0,984	0,991	0,859
happiness								1	0,804	0,875	0,829	0,854	0,862	0,872	0,676
"life cycle"									1	0,985	0,993	0,988	0,974	0,980	0,891
brief										1	0,991	0,994	0,986	0,990	0,877
design											1	0,997	0,991	0,985	0,893
transport												1	0,991	0,991	0,885
density													1	0,977	0,873
neighborhoods														1	0,861
yard															1

The validations of these hypotheses were performed by analyzing the scientific literature worldwide and a statistical analysis of appropriate articles in the Elsevier ScienceDirect bibliographic database. The scholars of this research integrated research design enrichments to derive greater reliability of the hypothetical relationship between COVID-19, the housing policies of pertinent countries and cities and how their residents behave pertinent to their green housing demands. The validations of these two hypotheses were performed by applying scientific literature (see Chapters 3-5) and statistical (see Chapter 2) analyses.

The establishment of green housing trends both on the micro- and macro-scope was performed by applying an analysis of scientific literature (see Chapters 3-5) during the Seventh stage of the model.

The numeric data obtained pertinent to the presented conclusions were made based on the Green Housing Topic Model.

Table 2. Key words reflecting user satisfaction with green buildings and the life cycle of a green building as well as colored cells in which the darkness of the color demonstrates the number of published articles (the darker the color, the greater the number of published articles)

year	"big picture"	personalization	customization	convenience	"quality of life"	"human-	satisfaction	happiness	"life cycle"	brief	design	construction	commissioning	operation	utilisation
2020	10	38	109	113	130	15	166	19	338	237	994	853	221	660	90
2019	9	26	117	81	131	7	183	24	357	233	913	781	251	674	85
2018	5	33	99	60	108	14	162	15	353	211	847	716	257	567	78
2017	13	21	94	66	102	4	148	7	365	191	909	783	253	612	71
2016	5	18	74	54	97	5	119	14	295	180	718	651	205	481	49
2015	2	14	53	50	70	3	103	9	257	128	614	523	178	394	49
2014	3	9	49	38	65	3	74	8	197	108	467	385	147	327	44
2013	6	12	32	30	48	2	52	7	115	86	302	267	118	218	37
2012	5	2	36	30	64		59	3	128	92	330	278	122	211	32
2011	4	8	21	21	57	3	38	8	102	65	341	309	94	199	21
2010	4	3	31	24	35	2	44	9	97	63	211	184	99	159	10
2009	1		10	15	24	1	14	1	47	28	108	95	41	77	11
2008	1	3	16	5	18		24	3	56	51	132	109	57	84	15
2007		3	9	5	10		6	3	26	28	80	57	33	48	8

2006	1	1	6	5	9		18	2	55	25	113	87	45	70	1
2005	1		2	6	6		6		24	11	46	32	13	21	2
2004	1		1	1	4		3		7	6	26	22	11	11	1
2003		1	1	1	2		2		3	9	22	17	10	12	1
2002		1	1	1	4		1		6	3	23	22	7	10	5
2001			1	1	2		3		6	2	14	11	3	6	
2000			1		1				6	4	12	12	3	7	3
1999			2	1	2		1		3	1	7	7	2	5	1
1998			1				1		1		5	4	1	2	

5.2. Sustainable housing

5.2.1. Changes in the way of people and communities live, interact and work, and the COVID-19 pandemic

The number of publications about COVID-19 on Web of Science (WoS) has been growing this year and more than 6,000 references are now available, as it has on ScienceDirect where more than 8,000 references can be found, but, in both cases, less than 1% of them deal with buildings or the built environment. A more focused research, however, shows that various journals published articles dedicated to the built environment in the context of the COVID-19 pandemic, analysing potential preventive measures or discussing this issue through the lens of sustainable development [119]. However, from another viewpoint, every service unit has needed greater consumption of energy, water and cleaning products due to the reduced capacities of outside services, e.g., the schools, shops and restaurants that have ceased being users [119].

Lockdowns have changed the way people and communities live, interact and work, and the COVID-19 pandemic reminds us the necessity to make the built environment resilient, including outdoor spaces, but especially homes, offices, entertainment facilities, public buildings and other indoor spaces. How can the concept of public health and well-being be adjusted to the context of a future with evolving and transformed living places? Learning from this period of physical distancing, this research integrates wellbeing and hygiene in buildings, highlighting possible responses both for new and existing buildings. The following key categories of public health and wellbeing recommendations for sustainable, safe and healthy housing have been selected: water consumption and wastewater management; solid waste management in cities; sharing, adaptability, and flexibility of living spaces, ensuring enough space per person, and adding compliant functions to buildings; reclamation of the basic archetypes and principles related to indoor air quality, thermal comfort, and sustainable architecture; visible and accessible green spaces and elements; electromagnetic fields and housing automation; building and décor materials and products for interior design. The recommendations from the aforementioned categories can serve as a basis for local health agencies, public health experts, policy makers (tax incentives tied to building refurbishment), and designers in speaking up for policies and actions aimed at promoting and maintaining physical and mental wellbeing in healthier living places [120].

The spread of SARS-CoV-2 with its extended lockdowns, school and university lectures moving online, and millions of people forced to turn to teleworking and spend most of their time at home has changed the way of life in home spaces. The pandemic has also made an impact on real estate values, with some characteristics becoming more desirable, while others fell out of favour. A group of university researchers are presenting their ideas in this brief study. They are experts in public health and architecture-related health issues and have been addressing the health problems related to modern urban life and homes for many years. This aim could promote closer and broader scientific links between medicine and architecture to improve the wellbeing of people in any environment, with emphasis on urban settings [121].

When, on 11 March, the World Health Organization (WHO) declared the COVID-19 outbreak a pandemic, the Italian Government imposed severe lockdowns with extremely restricted movement. As people were forced to stay indoors, all their life happened at home where they ate, slept, exercised, worked, socialised and engaged in other activities. Evidence shows that housing is a significant determinant of health. The lockdown measures related to COVID-19 response and their impact on mental health and wellbeing are, therefore, an interesting area to explore. In Europe, Northern Italy has been one of the most affected regions by the pandemic, and the authors of this study carried out a large online survey of 8,177 students from a university institute in Milan. Our analysis shows a link between poor housing and higher risk of lockdown-related depressive symptoms. Among surveyed people, those reporting a drop in performance when they work from home were more than four times more likely to report depression as well. Housing design strategies should focus on larger and more liveable living spaces facing green areas. Authors argue that a stronger multi-interdisciplinary approach is needed to investigate the ways the built environment can affect mental health. Such approach, where sociology, epidemiology, public mental health, environmental health, and urban planning intertwine, would benefit decision making and inform housing and welfare policies aimed at ensuring the wellbeing of people [122].

The COVID-19 pandemic has changed many aspects of our life and is offering an opportunity to change the way we design our living spaces. A comfortable and healthy home is an important contributor to mental and physical wellbeing. Based on the latest documents, including peer-reviewed papers, news, media articles, blog posts, and expert opinions, this study presents a critical review of COVID-19-related lessons and looks at changes in the sustainability requirements for residential buildings that can be expected. Lockdowns tested the three main aspects of residential buildings, i.e. comfort, environment, and health and safety. A major overhaul of these aspects towards sustainability is expected. Proper sanitation to diminish the probability of getting infected, new touchless technologies, and greener and more intimate spaces for better mental health are just a few solutions that can improve health and safety protection in our homes. The lockdowns have resulted in much greater consumption of household energy globally due to the increased time people spend at home. One example is the 30% increase in energy consumption during the daytime, as per U.K. statistics. These sorts of spikes in use had occurred during mornings previously, when people would be getting ready to go to work. U.S. statistics show an overall increase in household electricity use of up to 8% during lockdowns. Another key topic during the pandemic is waste management, because waste must be kept apart to prevent virus transmissions, since viruses can survive for 3–4 days on different surfaces [123].

It is widely accepted that health and housing are related. In Victorian England, for instance, people hypothesised links between poor housing and ill health and were looking for solutions; indeed, better sanitation and slum clearance did much to improve health. Soon many countries followed suit, Italy among them. A growing body of knowledge about infectious diseases and illnesses made people more aware that the quality of housing is an important factor for physical and

mental wellbeing. This has been recently reaffirmed by the WHO and vividly reminded by the COVID-19 pandemic. The built environment, and in particular housing, where people spend lots of time, is a significant source of indoor pollutants, especially in bad-quality housing generally occupied by very low income households. WHO 2011 estimates attribute 13 deaths per 100,000 inhabitants to low indoor temperatures, 2–3 to radon, and 7 to environmental tobacco smoke (ETS) per year globally. In terms of disability-adjusted life years (DALYs), 40 DALYs per 100,000 children are annually lost due to mould in homes, 577 DALYs per 100,000 children younger than five are caused by solid fuels as an energy source in homes, 31 DALYs per 100,000 inhabitants are lost each year due to traffic noise exposure, and 22 DALYs per 100,000 inhabitants due to lack of home safety features. The use of solid fuels in homes is also responsible for 17 deaths per 100,000 children [124].

COVID-19 lockdowns attended by economic shutdown and social isolation have disrupted individual lifestyles and society's priorities with serious sustainability implications. Grounded planes, as well as lower vehicle traffic flows and industrial activity reduced society's ecological footprint, as homebound families turned to non-commercialized leisure modes and social interactions. But social isolation has hit mental and physical health, and economic recession has also caused adverse effects exacerbating issues of underconsumption and poverty [125]. The pandemic, as some sustainability researchers believe, could potentially speed up the progress towards a future of more social fairness and better environment protection [125, 126]. We have been given a rare opportunity for putting together a sustainable transition towards broadly-adopted low-carbon solutions with both shifts in individual lifestyles and systemic-institutional reforms driven and implemented by multiple stakeholders [125, 127]. The changes caused by COVID-19 are a source of both worry and hope for organizations engaged in the advancement of sustainable development. The source of hope have been palpable short-term environmental benefits such as pollution decreases [125, 128] brought about by government measures. These events have demonstrated that policy makers can and have the will to introduce systemic changes away from an endless work-spend cycle and non-stop consumerism [106, 129]. Unfortunately, counter-pandemic measures have also led to adverse effects with serious sustainability consequences: they have unsettled sustainable development goals reversing, for the first time in 30 years, the progress towards lower poverty and misery [125]; deprived millions of children of access to education; led to social isolation to the detriment of mental and physical health [125, 130, 131]; and undermined the efforts to make people less dependent on the use of plastics [106] and individualized modes of transport [132], among others.

Faced with the devastating COVID-19 pandemic, people were suddenly forced to change many aspects of their usual lifestyles—an unprecedented event. But besides adverse effects, the COVID-19 pandemic can also push individuals towards environmental responsibility. The authors of this study provide a comprehensive analysis of shifts in pro-environmental beliefs and behaviour catalysed by the COVID-19 pandemic with a focus on the comparison between recycling and consumption reduction pre-COVID-19 with intentions post-COVID-19. The authors analyse a survey conducted during the national March–April 2020 lockdown imposed in Israel and validate the behavioural model using a generalized ordered probit estimated on a sample of 296 respondents. The findings show that shifts in behaviour towards pro-environmental approach are driven by threat and coping appraisal [133].

To contain the spread of a new and unknown highly contagious virus with relatively high mortality rates, humanity seems to have no choice but to limit social contacts and put an emphasis on personal hygiene. The pandemic has hit a heavy blow to the world economy; the energy sector suffered as well. As people are forced to stay at home, energy and water consumption in the residential sector has gone up. Using EnergyPlus software packages, this study looks at a household in Kragujevac, Central Serbia, and analyses four simulated scenarios for the month of March 2020

to discover correlations between the way people behave and the residential consumption of natural gas, electricity and water in unforeseen circumstances, such as the COVID-19 pandemic. The behaviour of people was tracked at a one-minute time step, taking into consideration the number of household members, their habits, occupation, age, lifestyle (in line with socio-economic and cultural circumstances), and the pandemic-related measures taken by the Government of Serbia. Energy consumption at the level of Kragujevac for the past three years has also been analysed, based on the data available from public utility companies distributing natural gas, thermal energy, water and electricity, as has the quality of air for the same time period, in view of its dependence on mobility and energy consumption patterns [134].

All areas of socio-economic life have been affected by the COVID-19 pandemic and the world has been changing rapidly in recent months with concerted efforts focused on ensuring public health, and then, in the next phase, looking for means to jumpstart economic recovery by resuming the human activities. Adequate housing has proved to be an important means of ensuring the well-being and health of the population. At the same time, housing is a point of stability from which all efforts start. This research, based on data provided by the National Institute of Statistics, the Quality-of-Life Research Institute, Eurostat and reports from specialized European organizations, aims to call attention to a number of housing affordability problems in the general picture of housing at the national level in Romania, looking at both the issues that existed before and new issues related to the COVID-19 pandemic. The role these issues play in access to affordable and adequate housing is analysed, the emergence of new risk groups with limited access to housing discussed, the impact of the pandemic on the ability of households to pay their bills examined, and evidence that the effects of the crisis amplify housing insecurity provided [135].

5.2.2. Necessary changes in built environment during the pandemic towards sustainable living

The COVID-19 pandemic forced people to stay indoors and work from home, but even before this health crisis they spent around 90% of their time in buildings. We need a radically new take on the design and operation of buildings. When Indoor Environmental Quality (IEQ), which directly affects the well-being and comfort of occupants, is compromised, occupants become more exposed and vulnerable to many diseases that can be exacerbated by both economic and social factors. The estimated annual cost linked to sick building syndrome in commercial workplaces is between $10bn and $70bn in the United States alone. We need to understand ways we can ensure proper design of parameters that drive IEQ, as well as ways to operate buildings achieving ideal health-benefiting IEQ. IEQ offers many research opportunities, but now more than ever we need a systematic understanding of the way IEQ factors work for or against occupant health. Extreme events, a global pandemic among them, call to provide occupants, facility managers and designers with pragmatic guidance on ways to mitigate health risks in buildings. This research gives answers to ten questions related to the effects of buildings on occupant health and can serve as a basis for future work offering insights for new lines of research and discoveries [136].

In research on housing, one of important parts is looking at health-related aspects in indoor environment. This research presents an overview of the latest research on occupant health evaluation in residential buildings and examines some of the key impacts people experienced during the lockdowns. The authors analyse satisfaction and dissatisfaction across ten UK housing typologies, representative in this and other contexts. Lack of regular physical exercise, lack of vitamin D from sunlight, excessive food consumption, mental health, lack of good air circulation indoors, and issues with indoor air quality are the general health concerns in this extended period of lockdowns and restricted mobility. Excessive noise from upper floors in blocks of flats or from shared walls and gardens/communal spaces in closely-spaced residential areas, and issues of privacy

to maintain social distancing measures are the other concerns discussed. Accessibility to the nearest outdoor spaces (a backyard or garden), noise and privacy issues, adequate indoor air circulation, adequate natural indoor lighting, opportunities to do physical exercises, and impacts on general health are evaluated. The earlier reports from various housing studies suggest that user satisfaction is important in indoor environments. As the COVID-19 pandemic hit, this field of research seems to have grown in importance as people are forced to spend long hours indoors and their thermal comfort and general comfort have to be maintained [137].

A year has already passed since the first cases of COVID-19 were detected and the novel SARS-COV-2 virus identified. The world has responded with a range of decisions. A few of the things we have learned from this complex COVID-19 crisis with interlinked political, social, public health and economic dimensions, testing the world's ability to take measures, have a direct relevance to the climate crisis we are facing and our aims to achieve broader advances in sustainable development. First, the scientific community actively contributed to the handling of the COVID-19 pandemic and proved its ability to generate great quantities of new practical knowledge in a record short span of time. By 13 October, Pubmed, a database of research papers focusing on health sciences and biomedicine, offered over 63,000 hits for the search term "COVID-19" and the number of publications keeps growing. The number of search hits for "climate change" is, in contrast, only 53,000 papers since 1975– a sign of huge differences in scientific and societal priorities. But faced with a sense of urgency, priorities and incentives can be aligned to push the scientific community towards producing new knowledge on climate change at the same pace and scale as in the case of COVID-19. Second, COVID-19 has shown that scientific research needs robustness even when we face an emergency. Hasty research of poor quality risks contributing more noise than actionable knowledge and can mislead public opinion or decision makers on vital issues; the Retraction Watch database has so far identified over 35 retracted COVID-19 publications. Third, COVID-19 has been a notable example of blurred lines between science and policy, at least in countries where leaders were keen to base their decisions and communication strategies on science, rather than disregard it. COVID-19 is striking not only because of the scale and pace of scientific production—the speed of putting new knowledge to action has also been impressive. Nonetheless, mere behaviour changes among people during the COVID-19 period has been shown to be insufficient. Governments must engage in ambitious and sustained policies in their pursuits of structural emission reductions. One such example might be an acceleration pertinent to the development and deployment of cleaner energy [138].

The natural environment can suffer negative effects from construction activities and the concept of sustainability has, therefore, been introduced in the construction industry. The construction industry, according to the United Nations Environment Program, generates 33% of CO2 emissions, 25% of waste production, and 30% of all annual waste products. It is, therefore, important to ensure sustainability in residential buildings with an aim to reduce air pollution and greenhouse gas emissions, and improve the quality of life and health outcomes. The drive towards sustainability in construction and buildings creates new jobs and business opportunities, boosts energy security and productivity, and has also resulted in the promotion of assessment systems to increase sustainability, declarations to preserve the environment, and the development of various international policies [139].

Sustainability is an integrated part of construction processes and the building itself, and construction companies have a range of building sustainability assessment tools (BSATs) available to promote economic, environmental, and social sustainability by meeting design and construction requirements. The number of registered tools is currently more than 400 [140]. Over the last three decades many green buildings have been certified, and each new case makes the issue of the

development of sustainable residential buildings more prominent, starting a virtuous circle. The Leadership in Energy and Environmental Design (LEED), the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), the Building Research Establishment Environmental Assessment Method (BREEAM), and the WELL Building Standard are already established and recognised green building certification systems (GBCSs) that assist the construction industry in mitigating the environmental impact of buildings and achieving better performance throughout their lifetime [142]. Most of these certification systems, however, have been designed with a specific region in mind and different climate conditions, geographical features, and government policies may lead to sustainability differences across regions [139]. To address this issue, many researchers are already trying to transpose recognised green building rating systems to developing countries adapting them to their specific features, with examples ranging from Kazakhstan [142] and Iran [143] to countries in sub-Saharan Africa [144] and Qatar [145]. Rapid changes in the living conditions around the globe mean that existing green building rating systems need to be constantly updated in this respect, too. The COVID-19 pandemic and the related lockdowns hit our societies everywhere, disrupting almost every part of daily life, including business, lifestyles, healthcare systems, education, economy, and tourism. Such unexpected changes, with people stuck at home for long durations, brought us to a new reality. This new reality should be analysed and taken into account in future decision-making. Since the COVID-19 pandemic and the changes it brought will likely stay with us even when the pandemic is over, many people in academic circles are re-examining the current sustainability approaches pushing towards new horizons [139]. Mohammadian et al. [146] argue that four new sustainability pillars, directly or indirectly interrelated, namely, educational, cultural, technical and political ones, should be added to the conventional group of three, which includes economic, environmental, and social pillars. Other researchers state that the main focus in LEED, BREEAM and other current sustainability rating systems is the environmental aspect of sustainable development (indoor environment, energy), whereas the social aspect lacks proper attention [147]. Possible effects of the current pandemic on the short-term and long-term transition of sustainability have been analysed by Kuzemko et al. [148]. They predict a fall of electricity prices and demand in the energy sector. Investments could move away from current industries and carbon-intensive fuels. Globalization and interconnectivity conventions could be challenged, leading to changes in politics and multi-scalar policies. The pandemic could also be an opportunity and impetus to move away from unsustainable practices towards more sustainable ones, for example, to exchange driving for walking. It is not the first epidemic to leave a mark in the built environment: cholera and plaque pushed towards the development of green spaces and new wastewater routes; a fight with tuberculosis led to the increase of sunlight in housing units; and the SARS-COV-1 outbreak led to the improvement of ventilation systems [119, 139].

5.3. Green housing

The real estate industry was severely affected by the COVID-19 in both the residential and the commercial sectors due to travel and site-visit limitations, rent sustainability issues and a decrease of or higher uncertainty about disposable income [149]. The real estate market, as for other productive and commercial sectors, in the short and mid-run, will not tend to move independently from the context of economic variables [150]. During the lockdown, houses became more important. It can be assumed that household preference of a new demand could emerge after this crisis making households looking for more comfortable houses since this asset will increase its importance for living and working. Similarly, the commercial real estate sector will change due to

lower rent sustainability. However, the main expected change is related to the building type and the standards requested by tenants in the new economic environment. Household investment prospects will change. Housing demand will need products (new or recovered) suitable for the times–high-quality properties capable of offering a safe and healthy living and working environment. The COVID-19 emergency highlighted that domestic spaces have become obsolete from a functional point of view, especially in current times of smart-working and minors being forced into social and home isolation due to unpredictable health emergencies. Residential and office real estate sectors, once distinct, today tend to overlap with each other. The housing market will be stable, but the change in commercial real estate markets will accelerate [151]. For real estate and property owners and users, there may be changes in credit usage, rental and contracts.

COVID-19 put the spotlight on health protection in buildings [152]. Existing efforts combined with new transformations may help address urban health inequalities stemming from socio-spatial structural injustices for the benefit of cities and all their residents to make them better prepared for, and more resilient to, COVID-19 and other similar crises we may face in the future [153].

Tokazhanov et. al argue that the COVID-19 pandemic has given us lessons, and changes in sustainability requirements for residential buildings should be expected and evaluated [123]. After COVID-19, new designs of living spaces may be introduced in sustainability requirements for residential buildings with emphasis on protective indoor health and safety measures, more intimate and greener spaces, new touchless technologies, better communication technologies for remote services and improved control of light, humidity, air quality, temperature, etc. For now, the building sustainability rating methods in existence have primarily favoured “environmental impact” and “energy performance”. A significant shift is expected towards an emphasis on “social and health” aspects. The authors suggest sustainability requirements for residential buildings need a review with a marked shift towards “social and health” aspects in sustainability rating methods for buildings, possibly with the support funds from expected COVID-19 stimulus measures for construction and current, as well as future green stimulus packages. Sustainable technologies mainly need to tackle the specific issue of improving the record regarding increased consumption of energy and water as a response to environmental needs. “The development of novel building codes and green certificates for the post-pandemic residential buildings and/or the modification of existing codes and certificates considering particular pandemic needs” are seen as future efforts driven by requirements with a view to resilient design solutions and possible pandemic scenarios [123].

To cover special pandemic-related requirements, this research [139] proposes a particular set of sustainability indicators. The focus on particular sustainability pillars is different in various GBCSs (BREEAM, LEED, WELL, CASBEE), as has been their response to pandemic resilience requirements. Some green certificates (GBCSs) have placed a lot of attention in a human-centered assessment of the sustainability of both residential and non-residential buildings and a reflection on the benefits of green buildings in the COVID-19 period is addressed [154].

Insufficient readiness for waste and wastewater management has been noted in all GBCSs and they all need modifications to improve their adaptability to pandemic conditions in line with existing and emerging post-pandemic requirements. A realization has dawned that modern life is possible without drastically harming the environment. It has involved taking a look at what the globe might look like without the use of fossil energy sources. This has encouraged hope that people could survive this pandemic while ending up in a healthier, cleaner world [139].

Air pollution, air quality improvements, wildlife, global migration, sustainability waste management, and waste fires were the focus of the researchers [151] who analysed a summary of the existing reports on the impact of the COVID-19 pandemic on the environment. Many regions—Italy, France, Spain, Los Angeles, and Wuhan in China among them—observed a noticeable drop in

air and water pollution. The crisis saw a rapid growth in health waste threatening the environment [151].

An analysis of occupant health in buildings by Awada et.al [136], covering both normal times and extreme events, the COVID-19 pandemic among them, shows that undermined Indoor Environmental Quality (IEQ) may expose occupants to a higher risk of catching many diseases exacerbated by both economic and social forces. The estimated annual cost linked to sick building syndrome in commercial workplaces is between $10bn and $70bn in the United States alone. During a global pandemic and other extreme events, occupants, facility managers and designers need pragmatic guidelines on ways to reduce health risks in buildings. An interdisciplinary approach may help and common standards and frameworks should be established with occupants rather than the building as the main focus. We should find ways to design buildings that support health and happiness [136].

The ability to recreate in public green spaces was seriously affected by the COVID-19 pandemic. To compensate this restriction and feel like they are away while at home, people turned to houseplants and outdoor green views. Research shows that exposure to more greenery had positive effects on the mental health of students forced by COVID-19 to spend most of their time at home [152].

The COVID-19 pandemic has hit many industries, with solar energy among them. Malaysia, in its efforts towards low carbon society beyond COVID-19, has plans to install rooftop solar panels, new grids, and LED street lights and earmarked about US$ 2.9 billion for that purpose. To accomplish this vision, the government, businesses and small players should work hand in hand [153]. Consequently, this article has undertaken a review of the current status pertinent to renewable energy in Malaysia. Furthermore it also reviews the initiatives taken to promote solar photovoltaic (PV) technology before the pandemic for meeting energy demands via a low-carbon pathway.

Energy demand is often uncertain, and the COVID-19 pandemic has only made things worse. Researchers [154] investigate the impact of the COVID-19 confinement measures on energy demand in buildings and use Urban Modelling Interface to simulate various scenarios. The COVID-19 outbreak comes in waves and a few more of them are possible. We should prepare for their impact by understanding related seasonal energy patterns and performance and with appropriate new policies able to withstand future long-term shocks. It is vital to set new building standards for extreme crisis conditions with guidelines for building design, ventilation rates and lighting/equipment power density in an effort to support city- or even region-level policymaking for planning new areas, their energy supply systems and infrastructure, design of confinement measures, and energy system options to make sure different buildings will not be short of energy [154].

Urban design will inevitably be affected by the current COVID 19 pandemic highlighting the need for scalable smart city solutions, emphasising the importance of public health and safety, and exposing the need to invest more in public health care and infrastructure in the built environment [155]. This study [136] shows that architecture and urbanism have a potential in epidemics control and prevention and can actively contribute to human health. The authors investigate links between the scale in the built environment, epidemiology and proxemics, as well as between population density and mortality rates. Solutions through architecture and urbanism are possible at multiple levels from individuals to shopping, transport and mobility ideas. They can be individual distancing and isolation; building-scale hygiene solutions; humidifying, ventilation, and filtering for indoor air control; social interaction solutions in the form of public spaces between buildings; intermediate housing; the scale and distribution of remote work; smaller shops closer to home; autonomous taxies, shared rides, bicycling, and walking; and mixed solutions spanning entire neighbourhoods.

We need to determine the role for architecture and urbanism in pandemic-related social resilience management.

Kapecki [160] examines the impact of humanitarian, financial and environmental crises on sustainable development with a focus on housing. Crisis-hit economies, at local scale or globally, suffer economic, ecological, financial blows, and now, because of the latest COVID-19 crisis, a humanitarian emergency. Because of that the development of a sustainable economy, and sustainable construction in particular, is left on the sidelines [161].

The author believes that this catastrophe will teach us a lot and will leave us more open to all activities. Among the activities, sustainable construction should play an important role. In the housing industry, green and sustainable, energy efficient construction so far makes only a small share of total residential construction, but in public buildings sustainable construction has dominated the market. There are wide gaps between residential and public construction and lack of green housing may make competing with the achievements in public architecture difficult. As countries imposed lockdowns one after another, some of them plunged into economic stagnation. The lockdowns also revealed a lack of safe housing so important for survival during the pandemic [162].

5.4. Countries, cities and housing in the era during and post COVID-19

There would be considerable benefit in having more interdisciplinary researches focusing on the analyses of three-way interactions pertinent to COVID-19. The interest is on the impact the related housing policies of countries/cities have on green housing and the betterment of the lifestyles for their residents. Conversely, it is also important to investigate how the residents themselves as well as the housing policies impact the dispersion of COVID-19. Such analyses need to treat all the named components as interacting and, thereby, have an integrated methodology as their bases.

5.4.1. Real estate policy in countries and cities: responses and challenges

COVID-19 disrupted the normal flow of life in the United States, with state and local governments issuing orders to stay at home and allowing only essential businesses and services to stay open. Communities across the country were affected. With no vaccines or medical treatments available, social distancing interventions were a necessary move to contain the virus, but they also meant crushing economic costs to businesses and people. Among the direct impacts are job losses, reduced hours and incomes, food and housing insecurity, and permanently closed businesses. Even ordered to stay at home, people still can go out for outdoor exercise. In their effort to give residents spaces for safe exercising (and commuting) in view of the two-meter social distancing recommendation, several cities, including New York City, have banned vehicular traffic from certain streets leaving them exclusively to pedestrians and bikers. New Yorkers were offered about 11 kilometres of open streets in and around parks. Recently the city announced new plans to add 160 more kilometres, add additional bike lanes and widen sidewalks in May. Similar measures have been introduced in Seattle, Oakland and San Francisco [163].

Some experts even suggest that telework becoming a new normal will make living in a large city less desirable and people, no longer attached to their old offices, will prefer less populous, and thus more affordable, places. Politico, a political journalism company, published an article titled “The

Death of the City", which argues: "For the first time since the earliest cities emerged in the Fertile Crescent some 6,000 years ago, concentrated urban centers no longer have a monopoly on the economic and cultural connections that make civilizations tick forward" [164].

In an attempt to make tenants, and sometimes landlords, less burdened, many countries have introduced changes in their real estate policies [165]:

- The United States is a country where state and local authorities are in charge of many decisions, and evictions have been temporarily prohibited in at least 34 states. The federal government also prohibited evictions from a property with a federally backed mortgage loan or federally subsidized housing for a term of 120 days. Citigroup, JPMorgan Chase, and other major mortgage lenders suspended mortgage payments. Construction has been suspended on all projects in some U.S. states, with a few exceptions, medical facilities among them.
- Some countries in Europe are providing temporary mortgage relief, have suspended evictions or both, France, Germany, Italy, and the U.K. among them. Mortgage and rent payments have been suspended both for commercial and residential tenants in various European countries. France, Italy, and other countries have suspended construction. Official tax reliefs have been granted to retailers in Europe, while banks have been urged to be lenient and refrain from foreclosures for late payments.
- Some countries in Asia, Singapore among them, are thinking of new laws to grant six-month protection to commercial tenants who cannot pay rent. Some Asian landlords have offered temporary rental rebates and rent discounts.

Tenants, owners and other entities have been offered a range of support measures around the world. These include a freeze of rent increases, rent reductions, suspended evictions, rent payment subsidies, and rental contract extensions for tenants; deferred taxes, suspended foreclosures, assisted bank lending, mortgage forbearing, and mortgage payment support for owners; and, in general, emergency shelter, support for construction industry and utility bill payment support [166].

In response to COVID-19, countries introduced a range of crisis-response measures in their housing policies, such as suspended or limited rent payments, tax reliefs for mortgage borrowers, suspended evictions or extra rules regulating landlord-tenant relations, eased macroprudential policy settings, expanded public capital spending on affordable housing supply, increased housing allowances, and relaxed land-use restrictions. Maintained for a long period, these measures may discourage from the expansion and maintenance of the housing stock, and put barriers restricting mobility, both labour and residential, in the longer term. Financial and economic resilience may also suffer [166].

In the ongoing COVID-19 crisis, cities are the first line of response. Measures are introduced nationally, but each city is a key to their implementation. They also act as laboratories of innovative and bottom-up recovery strategies. The shift towards green, inclusive and smart cities was already in progress before COVID-19, but the pandemic has sped up this trend. In our efforts to build back better cities, this policy note offers 10 key lessons learned from the crisis [167]:

1. Various countries suffered different impacts from COVID-19, but policy responses were often very similar across the world. It is important to customise approaches with local situation and the needs of local people in mind.
2. The health crisis has hit economic and social life hard with various cities suffering different consequences. Their recovery options and possibilities depend on their openness to trade, labour market structure and industrial composition.
3. A shift from the emphasis on increasing mobility towards expanded accessibility was already happening, but this rediscovery of proximity offers an opportunity to speed up the process by looking at urban design and planning and public spaces from a new angle.

4. The pandemic laid bare striking inequality across places and people, and this inequality was particularly glaring in large cities, where vulnerable groups such as the elderly, women, the poor, and migrants have been disproportionately affected.
5. Urban density is not the key factor in this health problem—the quality of urbanisation and structural inequalities are. Thus, tighter clustering will likely continue to be a source of benefits rather than concern;
6. A shit towards digital life, especially prominent and of great significance during the pandemic, will become entrenched as part of a "new normal", although remote work possibilities vary both within and across countries.
7. As people are becoming more environmentally aware, thanks to the "Greta effect" and "Zoom effect", circular economy and clean mobility have become more acceptable goals for transition, both socially and politically.
8. Governance has also been affected by COVID-19, due to changing trust in authorities, especially local politicians. In some countries people trust them more, but less in others.
9. Resilience needs more emphasis, as the disrupting effects of COVID-19 show. To achieve resilience, cities need to prepare for future shocks better by setting guidelines what persons have to take action, what their actions should be, at what scale measures should be applied and how to proceed in case of a crisis.
10. Strategy, policy, planning, and budget need an overhaul, and global agendas such as the Sendai Framework, the SDGs, and the New Urban Agenda can help with this aim.

After the initial short-term responses to manage the crisis, including local service delivery, workplace and commuting, social distancing, vulnerable groups, citizen engagement, support to business and other aspects, cities now have turned to long-term recovery strategies aiming to become greener, smarter and more inclusive ones [167]:

- Moving towards recovery, cities have taken many inclusive measures to address structural inequality and close the gap. Their measures include support to vulnerable households, construction and renovation of affordable housing, and local business support and employment.
- Looking forward to the future after COVID-19, many cities are already planning and making investments to ensure economic recovery is accompanied by environmental sustainability with a focus on energy efficiency and green modes of urban mobility.
- As digitalisation has been one of the key emergency responses to the pandemic, many cities are adopting smart city tools and making their use a more permanent aspect, at the same time monitoring the risk of spreading infection and staying alert. As cultural resources, municipal services, information, and participation are moving online, the virtual space is becoming more and more integral.

Even when the COVID-19 pandemic is over, COVID-19 will likely stay with us. The pandemic is a public health emergency with attempts to protect the health of people and limit the spread of disease. At the same time, the pandemic and its aftermath is prompting cities to look for new ways to deliver services, plan spaces and resume economic growth. In the context of the COVID-19 pandemic, 33 latest city strategies to achieve long-term recovery and ensure resilience to future shocks are summarised as broad categories of inclusive recovery and green recovery [168]:

- Inclusive recovery. Social inequality has existed before, but the COVID-19 crisis puts an additional emphasis on the importance to address this issue. The crisis has revealed shortages of affordable housing for low-income people and families, as well as the risks of infection the inadequate housing poses in lacking communities. For that purpose, many

cities launched public policy or investment initiatives with an aim to address the shortage of affordable and adequate housing and make disadvantaged residential areas better.

- Green recovery. As communities start recovering from COVID-19, cities will have many opportunities to emphasise ecological solutions in their economies, which, in addition to pathways to new jobs and long-term local economic growth, can also bring lower CO2 emissions, make communities better prepared for climate related risks (e.g. heatwaves or flooding) in the future, and improve urban environments (e.g. higher biodiversity, lower air pollution). As one city after another across the globe imposed lockdowns, car traffic significantly dropped in most cases, which, in turn, led to cleaner air and lower CO2 emissions. Regions with lockdowns saw a 50-75% decrease in road traffic flows and major cities experienced drops in rush-hour traffic congestion as high as up to 95%.

During the pandemic cities are upgrading various urban solutions to achieve maximum energy efficiency and reduce energy costs in their buildings after COVID-19. Experience shows that investment in energy efficiency and retrofitting not only reduces emissions but can also drive economic activity and job creation in the construction sector [169]. Urban density and urban form (compact or sprawl) are the advantages that could be used by all levels of government towards green urban economies with climate-resilient and low-carbon urban infrastructure. Designing and construction of green buildings and streets, renewable energy production and procurement, where feasible, and other similar solutions of spatial and land use planning with future in mind would help to achieve the goal [168].

The COVID-19 and the related pandemic caused serious disruptions in the construction industry hurting the housing sector. Households were also suddenly struggling with income shortages hitting their ability to pay for shelter. In response, governments introduced many different protection and support measures for tenants, mortgage-holders, lenders and builders [170]. To visualise the fallout of the crisis in the construction industry better, [170] looks at web-search data. Having then reviewed the measures taken by governments, OECD [170] concludes that, in addition to benefits, some of those relief measures might create inadvertent inefficiencies and make housing supply less responsive to the evolving needs of society and changing demand; hence, the measures have to be phased out as planned. Recent empirical findings led [170] to a conclusion that immediate rescue measures should transition gradually to recovery-oriented policy settings that can support the development of sustainable, inclusive and efficient housing markets.

As COVID-19 was spreading, the pandemic hit the real estate sector around the globe. With countries scrambling to contain the virus, work in construction sites in many places stopped completely or to some extent, leading to loss of income and revenue for households and enterprises alike. Because of that various segments of the property market faced gloomy prospects to different degrees, as some countries introduced stricter lockdowns than others and at different times, and the public health crisis was also of different severity. The housing sector suffered a particularly serious blow, but governments were quick to introduce a wide range of measures to mitigate the adverse effect of the crisis on lenders, borrowers, builders and tenants. Among them are measures that aim to preserve near-term affordability. If maintained for an extended period, however, they may discourage businesses from the expansion and maintenance of the housing stock, and because of that, in the longer term, residential and labour mobility may suffer. Economic and financial resilience is another area that may be undermined. Kept up for too long these measures—most, if not all, meant to be temporary—can cause difficulties with achieving a robust recovery. They can also make the housing market less responsive to the evolving needs of society. As emergency support measures went into force, eviction procedures were suspended, mortgage and rent payments deferred for a time, and utility payments in some cases postponed. During lockdowns,

most national as well as local governments introduced certain measures to provide shelter for the homeless [166].

To facilitate the recovery of homebuilding and ensure that the supply of housing matches evolving demand and the needs of society better, land-use restrictions need to be eased. Greater benefits can be achieved if such reforms are part of an integrated spatial planning framework spanning various hierarchies and government sectors. The reforms should promote housing construction, make housing more affordable, as well as improve neighbourhoods and avoid excessive differences in the access to social infrastructure, transportation systems and public services across different urban areas. Another benefit of the promotion of new residential construction is that a requirement for new buildings to comply with certain environmental standards could speed up the move towards low-carbon economy. The COVID-19 crisis may lead to lasting interrelated changes in housing demand and work organisation that could be accommodated by facilitating construction and redevelopment. Living in lower-density areas and working remotely could be new preferences. Urban-rural divergences then would slow down or even be reversed relieving the current demand pressures in very dense areas. A growing uptake of remote work with flexible workplace would also mean that some office spaces in city centres would be free for conversion to residential units, if land use permits the change. Such shifts could help reduce the gap between regional home prices and, in turn, residential segregation [166].

5.4.2. COVID-19 and its possible effects on future homes

Affordable housing movements and the COVID-19 crisis are changing the definition of "quality housing". Alternative ways to organize and use living spaces and new models have been proposed [171]:

- New or adjusted forms of shared living, co-living models in particular. Issues such as human connection, flexibility and cost could be addressed by making this form of housing available to everyone.
- In light of the blurring lines between work and home life, homes could become multipurpose spaces where people live, work and spend their free time.
- Private Rented Sector (PRS), Build to Rent (BTR), multifamily schemes and other models of managed rentals. Technology could also facilitate real-time residential management.
- Lease-to-own, co-investment, ownership unbundling, collaborative forms of the reverse-annuity-based French viager system, and other tenancy-ownership options to access new housing.

In times of the COVID-19 pandemic, our homes are no longer just living spaces. They are now places where we work and exercise, where our children attend lessons or lectures. They have made room for new hobbies and hosted happy hours at home. Real-estate experts speak about changing homebuyer preferences due to COVID-19, and predict possible shifts in home design in view of this new normal [172].

As the COVID-19 pandemic hit, almost every aspect of our life has changed, including preferred locations and forms [173]:

- Suburbs give way to exurbs. With many people forced to work from home, commuting in no longer a tying factor limiting the choice of housing. Thus many people now prefer to leave cities with their soaring prices behind and favour more remote areas. Since telework and remote learning have settled indefinitely as typical forms, many have no intention of coming back. Closer suburbs are still popular too, but low supply and large groups of motivated

buyers are driving a sprawl. Among attractive features we still find proximity to the city, sidewalk-lined centers, and accessibility to shops.

- Notable changes have happened in the condo market. Condos are declining in popularity. One of the reasons is that the shared areas previously presented as added value in many condo buildings are now seen as risky inconvenience. Figuring out how to stay two meters apart in an elevator is too bothersome. People are now giving up their condo homes and moving to single-family houses: the range of amenities may be smaller, but you can remove the face mask as soon as you are inside. Another factor is the price, because even the cheapest city condos cost more than suburban homes where you also get more space. Both more space and a lower price can motivate the move.

COVID-19 has changed housing interior trends and Rizzato [175] analyses a few of them:

- Soundproofing and privacy. Big open plans seem to have fallen out of favour. No more kitchens, sitting rooms, dining rooms and leisure rooms combined in one space.
- Healthier spaces. Germ-resistant flooring and surface materials, smart toilets, air purifiers, new air and water filtration systems, indoor air quality monitoring, in-furniture auto-cleaning technologies, automatic cleaning, and ultraviolet lamps.
- Voice Control and user-friendly technologies. A shift caused by the need to avoid touching the buttons of an elevator and other surfaces.
- New spaces for new functions. Online shopping, drone deliveries, dedicated package drop-off areas for home deliveries.
- Greenery. A boom of indoor gardening and vertical gardens is expected. They can improve indoor air quality in our homes and reduce stress [174].

The COVID-19 pandemic has forced limited or zero access to common areas and non-essential amenities in residential buildings. More and more people, however, expect luxury amenities in multifamily communities [175]:

- Health-related amenities. A gym or fitness centre, membership to local gym (discount or free), building-wide social distancing measures, contactless food delivery, free masks and gloves, hand sanitizer stations.
- Entertainment-based amenities. Outdoor grill areas, recreation rooms, rooftop deck or patio, basketball and/or tennis court, pool, movie theatre rooms.
- Convenience-based amenities. Free broadband internet and cable TV, in-building convenience store, package lockers, electric car charging stations, exclusive meal services and/or a virtual restaurant, video intercom systems, package alerts and mailrooms with mailroom management software, valet services, dog run or park.

Around four out of ten workers took up remote working for the first time; thus, many people are spending much more time at home. For families with children homes have also become makeshift playgrounds and schoolrooms. The current stock of housing, with issues such a lack of personal space, high-speed internet, outdoor space or natural light, poses the question of the adequacy of our homes. COVID-19 is not the first and hardly the last public crisis that may disrupt our everyday lives, and remote work may become prevalent in view of its current relative success. Public authorities should, therefore, review their planning guidelines with homes as places to truly live in, rather than just eat and sleep, in mind. As over the medium-term (at least) private developers of housing are likely to be in partially suspended mode, waiting to see the direction the market takes, ready-to-implement public housing projects are a great opportunity for nations to restart construction work, making sure it is safe to bring workers back on site, and this way to give their economies a much-needed boost. In the current climate of economic and financial uncertainty and rock-bottom bond yields, residential properties can be seen as an attractive investment for

prospective private landlords looking for ways to convert their cash to sources of rental income. The post-COVID period could, therefore, see the monetisation of housing, prevalent since the financial crisis of 2007–08, keeping up and going further [176].

Ogunnusi et al. [177] examine the effects of COVID-19 on real-estate-related deals and the prospects of the construction industry by means of quantitative measures. Built asset procurement professionals were surveyed and the results of this survey reveal certain issues with workflow and supply chain disruptions, new policies, workforce anxiety, as well as COVID-19 vs Force Majeure revisions in standard construction contracts. The necessity for virtual working and unique design considerations, however, presents new opportunities to modern procurement planning. The research by Ogunnusi et al. [177] can serve as a basis for those developing additional contingency plans and a new working strategy in situations of social distancing caused by the pandemic. The study by Gamil and Alhagar [80] looks at the effect of COVID-19 on the survival of the construction industry and classifies the impacts into different groups, including human and economic resources. The biggest impacts of COVID-19, as the study by Gamil and Alhagar [178] shows, are labour impact and job loss, the suspension of projects, cost overrun, time overrun, and financial implications. Bailey et al. [179] look at the impact of COVID-19 pandemic and its management with focus on construction projects were the pandemic has been slowing processes and leading to disruptions and delays. Legal implications, however, vary between contracts and across countries. Some projects were suspended and delayed. Businesses must assess health and safety risks in line with medical, scientific, and government guidelines. In indoor spaces, for instance, people face higher risk than those working outside. Whereas no one could foresee COVID-19 and its outcomes, it can be considered a case of force majeure, which in any standard form of contract (FIDIC among them) usually affords contract extension spanning the duration of the pandemic with no compensation for cost [179]. The findings by Shibani et al. [180] show that lockdowns and social distancing rules caused by the COVID-19 pandemic provided a serious hit to construction companies involved both in residential and commercial projects. In response, construction companies chose the strategy to stay on good terms with their suppliers and ensure the safety of construction teams [180]. Ataei et al. [181] review the immediate response of the construction industry to the COVID-19 pandemic and the challenges it poses looking at the impacts on projects related to timetables, delays, financial difficulties, as well as new and shifting regulations. Hook [182] argues that this pandemic may force some engineering and construction companies to look for funding and streamline debt, or risk bankruptcy. Engineering and construction companies face new realities in the future with changing markets and public infrastructure investment, as governments look for ways to jump-start recovery [182].

In the times of the ongoing COVID-19 crisis, Zillow has presented the TOP 10 housing trends for 2021 related to life in this environment in the nearest future. Zillow's top housing trends for 2021 are as follows [183]:

- 'Zoom Rooms'. Zillow surveyed Americans and discovered that the top reason they would consider a move, if they were to continue working remotely at least occasionally, is that they would prefer a home with a dedicated office in such case. In 2021, employers will give a clearer message about the possibilities of remote work in the future and this could encourage people to look for homes with more space, as tired of working in their kitchens people will want more permanent solutions for their work at home—to have a quiet dedicated corner. As of November, an increase of 48.5% was recorded year-over-year in the number of listings mentioning "home office" or "Zoom room".
- 'Homecation' Amenities. As people are forced to stay home and have lots of time, they are thinking up creative solutions to make themselves a vacation at home. In 2020, "pool" was

the most popular search term at Zillow, with “waterfront” and “dock” also in the top ten. Homeowners may also be looking for ways to add a touch of luxury at home with a relaxing rain shower or spa-like bathtub, and home buyers, according to Zillow, paid extra for amenities that make their home feel like a resort. A mention of a free-standing tub typically meant the listing sold for a price 5.5% higher than expected, while the keyword “spa-inspired” added a 1.8% price premium. The rise of telecommuting means that more people will be able to take permanent residence in their favourite vacation destination. Key West, the Jersey Shore and Cape Cod are just a few of areas typically considered vacation destinations with page views of for-sale listings there up nearly 50% YOY.

- Intergenerational Living. This form of living will become more popular as, for financial and health reasons, both young and old people move in with family. Today about 16% of Americans, according to Generations United, live in households of more than one generation, and the share of young people (Millennials and Gen Z, especially among renters) moving back in with their parents reached historical hights in 2020.
- Gourmet Kitchens. With fewer opportunities to eat out, the year 2020 inspired people to look for new things they can bake in their kitchens. In 2021, homeowners will want to go further in this endeavour and level-up with more new culinary masterpieces. As a result of social distancing recommendations, 41% of people value a well-equipped kitchen more than before, according to a previous Zillow survey. In the next year, more people are likely to prefer better-equipped space for their new culinary skills.
- Backyard Oasis. Social distancing recommendations have highlighted the importance to have a safe and functional yard and 41% of people, according to a Zillow survey from the Harris Poll, now value a large outdoor space more. A few easy touches and your backyard can become a relaxing oasis for the whole family with an additional benefit of a higher resale value of your home. Listings mentioning “firepit” sold at a 2.8% price premium, and “outdoor kitchen” added extra 4.5% to the price, according to Zillow. An addition of outdoor lighting and/or smart sprinkler systems also makes your backyard look more attractive to potential home buyers and may speed up the sale of your home up to 15 days.
- Smart and Safe Tech. Home disinfection has become a vital part of our daily lives, and smart-home technology is rushing to the rescue with products such as self-cleaning toilets, bidets and touchless appliances. These are often still niche products, but gradually they will become standard fixtures in home design. When social distancing rules will be lifted and guest visits will become a normal thing again, more and more homeowners will look for creative solutions to keep their spaces clean, but also chic. By incorporating thoughtful innovation into home products, robotic vacuums, electronic-assistant controlled lights, voice-activated faucets, and other features have brought into homes new ways of cooking and cleaning. Buyers increasingly see smart home technology as an attractive option. Listings mentioning a smart light sold seven days faster than expected, and those with a smart thermostat mentioned in their description sold six days faster than expected, according to Zillow. Looking for ways to keep their families safe and germ-free, homeowners will be more likely to add a new touchless faucet and similar fixtures and fittings to their homes.
- Small City Living. With ever more telecommuting opportunities, many people looking for a new home now have new ideas of where and how they want to live. As the need to be close to jobs in cities is falling, smaller, more affordable communities and wide open spaces may become the main preference for homebuyers in 2021. Search traffic data is already showing this trend. Pierre in South Dakota, Borger in Texas, Vernal in Utah and other similar small cities contributed most to the growth in out-of-town search traffic, compared to the

previous year; out-of-town search traffic in a dozen markets such as Jackson in Wyoming, Pierre in South Dakota and Hudson in New York doubled this year. In case of small cities, with populations between 54,000 and 137,000, newly pending sales have increased 34.3% since last year, and YOY pending sales have been positive since July. The preference to live in small cities will only keep growing as remote work becomes a more established practice and give renters opportunities to become homeowners.

- Health and Wellness at Home. Nationwide, people were quick to adapt to new restrictions, setting up mental wellness spaces or fitness clubs right at their home. In November, health and wellness areas were mentioned in 4.1% of homes listed for sale on Zillow. The number of listings mentioning "health and wellness" has been increasing since early summer and peaked in November with lockdown orders renewed and fewer daylight hours for outdoor activities because of the approaching winter. Physical health, however, is not the only priority homeowners have. Isolated from social activities and loved ones, people will be more inclined to set up their own private areas for their mental wellbeing activities such as meditation and reflection. According to Berks Homes, the number of homes with an extra bedroom in the basement or over the garage has increased this year. These new private spaces added to homes may be converted to meditation rooms, or become a quiet space to spend some time away from chaotic life.
- Pet-Friendly Living. Telecommuting gave many people the opportunity to spend all their day at home and better ability to take care of pets. Twenty percent of respondents surveyed by Nielsen in July said they had adopted one or more cats or dogs between March and June, compared to less than 5% over the same period last year. As more furry new best friends join families, the demand for pet-friendly rentals is growing and landlords use these added benefits to entice renters. According to Zillow, 73.1% of residential properties listed for rent allow pets. Because the number of families with pets is growing, Zillow reckons they will expect pet-friendly features in their next home. In 2020 Zillow analysed available data and found that listed properties with a fenced backyard mentioned in their description sold 6.8 days faster than expected and those with a pet shower or dog wash mentioned added a 5.1% price premium over similar homes with no such amenities.
- Rise in Demand for New Construction. Zillow has observed a significant increase in traffic of people looking for new construction homes, up 82% in the third quarter of 2020 YOY. This means more homebuyers are interested in the ability to personalise their home and want to live in a clean, new space. Surveyed by Zillow in 2020, over a quarter of households who bought a new construction home said their choice was determined by the wish to customize home features, while another 37% based their decision on the fact that everything in the home was new and never used.

BIM means that each building has a virtual counterpart used throughout its lifecycle—from its design and construction through its operational life until its demolition. This virtual counterpart makes it possible to track and analyse environmental metrics, energy consumption, and human activity patterns. Efficiency thus can be improved and desired outcomes (e.g. social distancing) promoted. Soon virtual counterparts will be used in the planning of and, later, adding adjustments to entire neighbourhoods and cities. But equity should be front and centre when this point-of-no-return will be reached [164].

The COVID-19 pandemic pushed up the demand for more space and less dense living environments among consumers. With the U.S. housing market bustling this year as Americans encouraged by extremely low mortgage rates and remote work opportunities are looking for places to relocate, the condo market has not gained much. During the coronavirus pandemic, people

looking for a new home preferred more space and privacy of single-family homes to dense cities. An exodus from cities to the suburbs in search of more space has been observed [184].

A new report by Zillow shows that more than a third (34%) of potential sellers prefer to stay out of the market for now, faced with uncertainties, mostly caused by COVID-19. An important role is played by financial anxiety: of the homeowners who are thinking of selling their current home in the next three years 31% say they are discouraged by the current precarious or uncertain financial situation, with 27% reporting recent employment changes with fewer hours or lower pay, and 17% mentioning a job loss or furlough; these reasons could make people less inclined to look for a new home. Another contributing factor is the uncertainty surrounding the place of work. A survey by Zillow shows that homeowners started to work from home more often in the past six months and this new arrangement is the most common change. Another survey by Zillow shows that two-thirds of people teleworking during the pandemic would consider looking for a new home if the ability to work from home occasionally stays after the pandemic. While homeowners wait for a clear signal from their employers when (or if) they will have to return to the office, however, those plans may be on the backburner. Almost 40% of the homeowners who are thinking of selling their current home in the next three years say they expect a more favourable sale price if they wait, suggesting they do not think now is the only time to get a good price, despite all-time high median sale prices, up nearly 11% YOY for the week ending 5th September. Sellers are once again optimistic, too: a Fannie Mae survey in September found a majority (56%) of people think now is a good time to sell, up from 29% with the same opinion in the spring. Potential sellers believe that home prices have not peaked yet. They are likely correct, but there is no clear 'right time' to sell, because prices always tend to rise in the long run [185].

Density is usually associated with higher rates of mortality from, infection with and transmission of highly contagious diseases, COVID-19 among them [186; 187]. An opposite conclusion can be drawn, however, from a U.S.-wide analysis of the relationship between COVID-19 infection and mortality rates and density in 913 metropolitan counties [188].

Connectivity makes a serious impact on COVID-19 infection and death rates. More in-depth research on measuring connectivity in cities and its impact on the spread of pandemic is, therefore, important. Future studies could reveal new aspects by developing and using more sophisticated internal connectivity measures, for instance, location-based social networks [189].

Confirmed virus infection rates are not related to density, but confirmed virus death rates are inversely related to it. This fact is unexpected, important and very serious with implications for transportation expenditures, regional planning, community design, urban redevelopment, congestion pricing, affordable housing, tax policy, smart growth, and almost all other urgent issues important to planners. It goes against ideas that, without data and analysis, might question the foundation of modern city planning that density is preferrable to sprawl, at least in some places such as urban and suburban centres [190].

The number of studies looking into the impact of density on highly contagious new infections is not high. In theory, people living in densely populated areas have more interactions with others, which may contribute to the rapid spread of contagion. But dense areas may also mean better access to health care facilities and higher adoption of social distancing practices and policies [90]. The findings by Hamidi et al. [188] suggest the spread of the COVID-19 pandemic is facilitated more by connectivity than density. The most vulnerable locations are large metropolitan areas with tight economic, social, and commuting links with a higher number of counties. With higher movement of people (tourists, businesspeople) both inside such areas and with outside locations, the risk of cross-border infections is also higher [185].

Every aspect of urban planning practices has been affected by this pandemic. With high unemployment rates, its economic impact is already obvious. Months of social distancing, staying a home, and the economic crisis will lead to societal impacts. Environmental impacts are also expected: both positive ones from changed behaviours and, without the right measures in place, recovery-related negative ones from rebuilding the economy. The severity of all impacts combined will determine political impacts. Finally, technological impacts may open new opportunities to find ways to respond and prepare for this new future [191].

Facebook expects to see half of its employees working remotely by the end of the decade, and this expectation is not tied to the pandemic. Meanwhile, seven in ten Microsoft employees would like to continue teleworking after the pandemic ends. Among surveyed employers, 94% stated that productivity did not suffer due to teleworking, 27% noted an improvement in productivity, and 73% expect that at least a quarter of employees will work remotely indefinitely, with close to half of those reckoning that 50% of their employees will continue teleworking even when offices are safe to return to. Various surveys predict a shrinkage of office footprints, which, in turn, will open new ways to solve longstanding urban problems as transportation and land-use patterns shift. Downtown areas often lack housing, so some of the empty offices might be converted to residential units. Such endeavours will demand extensive investments from building owners. Government incentives and zoning changes are likely to be required making it a long-term effort [164].

Although a home in the U.S.A. typical costs about $263,000, a sharp increase in the number of “million-dollar cities”, according to Zillow, was recorded in 2020, adding 45 new U.S. cities to the pool of those with a typical home value of at least $1 million. No larger increase has been observed in at least a decade. The number of million-dollar cities is now 312, compared to 104 five years ago. The significant increase over the course of 2020 is the testimony of considerable activity in the market last year and surging demand through most of 2020 caused by demographic trends and the pandemic, with home values going up almost 7.5% annually in November. The year before, in contrast, saw the lowest rate of home value appreciation since 2013. The list of million-dollar cities is typically dominated by areas with attractive natural surroundings, such as mountains or the ocean nearby. A great media package, including 3D imaging, virtual staging, and a floor plan with dimensions, give sellers a competitive edge [192].

Cities are making moves to protect homeless people. Among them Chicago and Los Angeles, where resources have been prioritised for emergency shelters, Baltimore, where vulnerable homeless residents aged over 62 are being relocated from emergency shelters to motels, and New Orleans, where homeless people were also moved to a hotel. Various modes of transport have been impacted by the COVID-19 pandemic and the impact is huge. With transit use declines of about 97% in Chicago and San Francisco, and 87% for subways and 70% for buses in New York, most transit agencies have cut their services down to hedge against financial loss. Other modes of transport also suffered with rider numbers at Uber 60–70% down in Seattle, and zero rides in New York where this type of services has been banned. Across major cities, Uber suspended its UberPool, a ride-share service. The story of bike sharing is different. Divvy in Chicago and other similar companies, in partnership with cities, offer their members attractive discounts during the pandemic. People increasingly are choosing biking over using transit as a safer option. Philadelphia is going with the trend and, to make its cyclists safer, has closed a 7-kilometer street to vehicles; biking in Philadelphia is up more than 150% [163].

The impacts of digitalised workplaces will go along with, and be reinforced by, the digitalization of education, shopping, and entertainment. More people will regularly shop for basic goods online and brick-and-mortar retail stores will be mostly devoted to offering experiences. These trends driven to new levels by the pandemic will result in huge areas of obsolete asphalt. Perhaps we are

not going see autonomous cars taking over roadways anytime soon and it might take several decades for this future to arrive, but the ever more popular ideas for converting parking areas to serve other purposes may be implemented sooner rather than later. The Christmas rush plays an important role in setting parking requirements, but this phenomenon may move increasingly online. In that case, the supply of parking spaces will exceed demand considerably. All these no-longer-needed paved spaces could then be converted for other uses such as urban green spaces or affordable housing. As people spend more time at home, they are likely to ask for more activities—from green landscapes to entertainment options—within a walking distance. How does the concept of land use change when people do everything at home: live, work, shop, study, and produce things? Does the concept of a residential district still have a meaning? How is it different from an office district, a commercial district, or an industrial district? The land zones set in the past may no longer correspond to the way people are actually living and working in the future. A more inclusive and flexible system will be required where people will be able to adapt. This trend opens many opportunities [164].

Industry 5.0 expects to resolve the increasing need for personalization, since Industry 4.0 was unable to accomplish such [193]. Industry 5.0 endeavours to personalize its products and services on masse, like never before. The experiences of its clients are also included in this process. Japan describes Industry 5.0 as “Society 5.0” – a revolution of “human touch” – as follows: “A society that orients towards the human being balances between a system of economic advancement and social problem resolution, which integrates cybernetic and physical spheres very well” [194]. “Vital entrepreneurship” and “vital marketing” are the activated goals of personalization including those companies that are constantly able to foresee and react to ever-changing client needs (by gathering and analysing data in real time). Such companies become a part of the daily lives of their clients [195].

Industry 5.0 is now seemingly progressing towards harmonious technological and societal systems that deliver a customization of products and services en-masse, which are all personalised [98]. An increased human–machine interaction is the primary difference between Industry 4.0 and Industry 5.0, according to [197]. It encourages personalized expressions among people by their use of personalized products and services. The emphasis in the work by Yin et al. [198] that regards the future of technology and personalization revolves around human centrality.

Unfortunately, there is very slow movement of the Internet of Things towards humanization. This has inspired Kaklauskas et al. [199] to foster the idea of humanizing the Internet of Things among academic and business communities. Analysing the affective internet of things, smart homes, ambient intelligence, affective computing, BIM, smart and interactive buildings and smart building systems constitute the presentation of the humanization of the Internet of Things by this research [200].

A number of researchers have also engaged in scientific studies focusing on individual thermal comfort and indoor air quality [201-210]. Personal comfort systems (PCS) are analysed next as an example. PCSs in laboratory and field studies can appear in different forms, such as ceiling fans, radiant or convective heaters and temperature-controlled surfaces on chairs, desks and floors. Certain systems and devices have been designed to address individual thermal variability by permitting people to control their own thermal status. Thereby people are able to adjust temperatures to the degree of comfort for themselves. The warming and cooling stimuli on surface bodily areas can affect the entire body's thermal sensation [211-2013; 204]; thus such systems are effective. A unique approach to PCS appears in the work by Wang et al. [203], who assess leveraging the time-dependence of human thermal perception. Embr Wave, which is a 6.25 cm2 wearable device, supplies dynamic, cooling or warming waveforms to the inner wrist. A substantiating work

of research is by Wang et al. [203], which concludes that this wearable device running on low power betters the thermal phenomenon, comfort and satisfaction over the entire body. Meanwhile a study by Lopez et al. [214] discovers that a whole-body thermal sensation works more efficiently by cyclic heating rhythms than it does by continuous heating.

6. The Affect-Based Built Environment Video Analytics

MICROBE contains a smart database management system, a smart database, an equipment subsystem, a model database management system, and an intelligent model database and user interface (see Fig. 4). The architecture of the MICROBE is analyzed below.

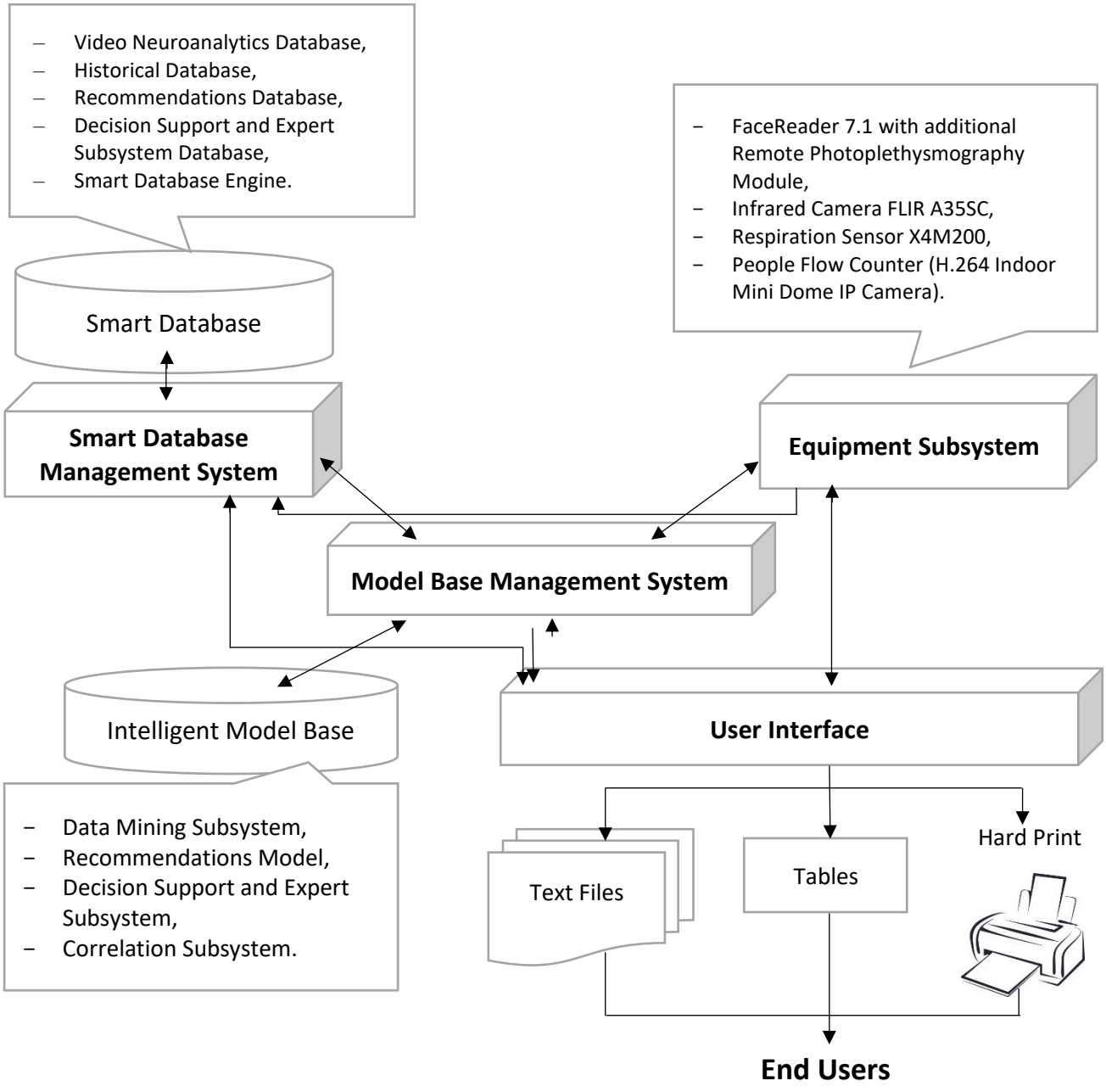


Figure 4. Architecture of the Affect-Based Built Environment Video Analytics

6.1. Smart Database and Equipment Subsystem

The smart database contains the developed video neuroanalytics, historical, recommendations, decision support and expert subsystem databases and the smart database engine.
The video neuroanalytics database collects the following data:

- emotional states (happy, sad, angry, surprised, scared, disgusted or a neutral state), valence and arousal: data measured by the equipment subsystem)
- affective attitudes (boredom, interest and confusion): data measured by the equipment subsystem
- physiological states (average crowd facial temperature, crowd composition by gender and age groups, heart rate, breathing rate): data measured by the equipment subsystem
- air temperature (°C), relative air humidity (%), average wind velocity (m/s), atmospheric pressure (hPa): data obtained from the Vilnius Meteorology Station; apparent temperature was also calculated using the online calculator https://planetcalc.com/2089/
- pollution (particulates [PM_{10}], nitrogen dioxide (NO_2), noise (dBA), carbon monoxide (CO) and sulfur dioxide [SO_2]): data gained from the local authority in Vilnius.
- data on the built environment of Vilnius and its municipal districts, obtained from experts in the field.

The historical database collects historical data from the video neuroanalytics, recommendations, decision support and expert subsystem databases.

The recommendations, decision support and expert subsystem databases are compiled with assistance from experts in the field, and contain data on sustainability and quality in a built environment.

Currently, the MICROBE smart database is capable of managing and merging above six layers of data and performing data mining. The data mining component evaluates the six layers of data from using ordered logit, KNN and ANOVA.

The equipment subsystem comprises biometric analysis devices for gathering remote data on facial emotions (using a FaceReader 7.1 with an additional remote photoplethysmography module), temperature analysis (using infrared camera FLIR A35SC), an X4M200 respiration sensor, and a people flow counter based on a H.264 indoor mini dome IP camera. Measurements of interest, valence, arousal and boredom levels were taken every second by the FaceReader 7.1 with additional remote photoplethysmography module. Seven sets of the equipment subsystem were manufactured and used at this time. The requirements for each set of equipment are as follows:

- High-speed Internet access with a minimum of 600 MB/s. This may be cable Internet access or two wireless networks of 300 MB/s each. The required upload speed is 50 GB/s. The system also requires an unlimited amount of data per month, and the quality of the signal strength should not be less than 4/5. A static external IP address is also needed.
- A grid connection.
- Optimal locations should be identified. The valence, arousal and emotional states (happy, sad, angry, surprised, scared, disgusted or a neutral state), affective attitudes (boredom, interest and confusion) and physiological states (average crowd facial temperature, crowd composition by gender and age group, flow of people, heart rate, breathing rate) of anonymous passersby are established from a distance of 20 m, and the breathing rates of passersby are established at a distance of up to 5 m.

6.2. Neuro Decision Tables

One of the most important stages in this analysis is the establishment of the multimodal criteria that define the alternatives, along with their values and weights. Once the system of criteria is established and the values and weights of these criteria are calculated, the utility degrees and priorities of the variants under comparison are established by applying the multiple criteria methods in [34, 35], which were developed by the present authors. The results from the analysis of the alternatives under comparison for an affect-based, multimodal video analysis process are presented in the form of a neuro decision table, in which the columns contain the n alternatives under deliberation and the rows contain the multimodal criteria and their values and weights (see Table 3). The neuro decision tables are supplemented with data from the equipment subsystem, the video neuroanalytics, historical, recommendations, decision support and expert subsystem databases. Experts in the fields of the alternatives under discussion can also supplement these tables. The decision maker places the not biometrics $X_1 - X_t$ criteria (the last three data layers (see Stage 7 "Development of the MICROBE")) and information describing them (units of measurement $[u_1 - u_t]$, values $[x_{11} - x_{tn}]$ and weights $[w_1 - w_t]$) in the neuro decision table. Meanwhile, the biometrics criteria $X_{t+1} - X_m$ (the first three data layers (see Stage 7 "Development of the MICROBE")) and information describing them (units of criteria measurements $[u_{t+1} - u_m]$, values $[x_{t+1\,1} - x_{mn}]$ and weights $[w_{t+1} - w_m]$) are captured by the equipment subsystem and the video neuroanalytics, historical, recommendations, decision support and expert subsystem databases.

Table 3. Neuro decision table

Criteria describing the alternatives	*	Weight	Measuring units	Alternatives under comparison					
				1	2	…	j	…	n
Not biometrics criteria: the weather conditions, pollution, economic, social, environmental protection and historical heritage data related to the municipal districts in Vilnius (see Stage 7 "Development of the MICROBE"))									
X_1	l_1	w_1	u_1	x_{11}	x_{12}	…	x_{1j}	…	x_{1n}
X_2	l_2	w_2	u_2	x_{21}	x_{22}	…	x_{2j}	…	x_{2n}
…	…	…	…	…	…	…	…	…	…
X_i	l_i	w_i	u_i	x_{i1}	x_{i2}	…	x_{ij}	…	x_{in}
…	…	…	…	…	…	…	…	…	…
X_t	l_t	w_t	u_t	x_{t1}	x_{t2}	…	x_{tj}	…	x_{tn}
Biometrics criteria: data on affective attitudes, emotional and physiological states and valence and arousal (see Stage 7 "Development of the MICROBE")									
X_{t+1}	l_{t+1}	w_{t+1}	u_{t+1}	$x_{t+1\,1}$	$x_{t+1\,2}$	…	$x_{t+1\,j}$	…	$x_{t+1\,n}$
X_{t+2}	l_{t+2}	w_{t+2}	u_{t+2}	$x_{t+2\,1}$	$x_{t+2\,2}$	…	$x_{t+2\,j}$	…	$x_{t+2\,n}$
X_{t+3}	l_{t+3}	w_{t+3}	u_{t+3}	$x_{t+3\,1}$	$x_{t+3\,2}$	…	$x_{t+3\,j}$	…	$x_{t+3\,n}$
…	…	…	…	…	…	…	…	…	…
X_m	l_m	w_m	u_m	$x_{m\,1}$	$x_{m\,2}$	…	$x_{m\,j}$	…	$x_{m\,n}$

*- The sign + (-) indicates that a greater (lesser) criterion value corresponds to a greater (lesser) significance for stakeholders

The MICROBE assesses the quality of the integrated built environment (pollution, the emotional states and affective attitudes of passersby, etc.) according to the compiled neuro decision tables,

and calculates the indirect use value of public spaces under analysis. The basis for performing this is the intelligent model base and its management subsystem.

6.3. Intelligent Model Base and Its Management Subsystem

The intelligent model database contains the following subsystems:

- The data mining subsystem;
- The recommendations model;
- The decision support and expert subsystem;
- The correlation subsystem.

A detailed discussion of the components comprising the intelligent model database appears below.

Data Mining Subsystem

Affective attitudes, emotional and physiological states, valence and arousal, pollution and weather conditions and other data related to the built environment under analysis need to be collected and analyzed in an integrated manner, allowing the establishment of over 20,000 of average and strong correlation coefficients. The data mining subsystem assists in discovering information and patterns in the aforementioned six data layers by applying the integrated MICROBE method.

The data mining subsystem is designed to decode the initial data representing the crowd's emotional state in order to provide logical evidence of what is happening in the crowd. Logit, KNN and MBP techniques for crowd mining are used in parallel with expert explanations. The results produced by the data mining subsystem are visualized to assist specialists and stakeholders in interpreting the data.

Global research conducted by Harley et al. [36] found that facial analysis is the single MICROBE technique for precisely recognizing emotional conditions, and supplementary techniques can be applied to precisely classify each emotional state. The long-term experience of the project partners supports this claim. In this way, the emotional states of passersby (happy, sad, angry, surprised, scared, disgusted or a neutral state), valence, arousal and affective attitudes (boredom, interest and confusion) was established every second using the FaceReader 7.1 with additional remote photoplethysmography module (see Fig. 5). The developers of FaceReader™ [37] state that this implicit affect measurement software can recognize facial expressions with an accuracy of 90%.

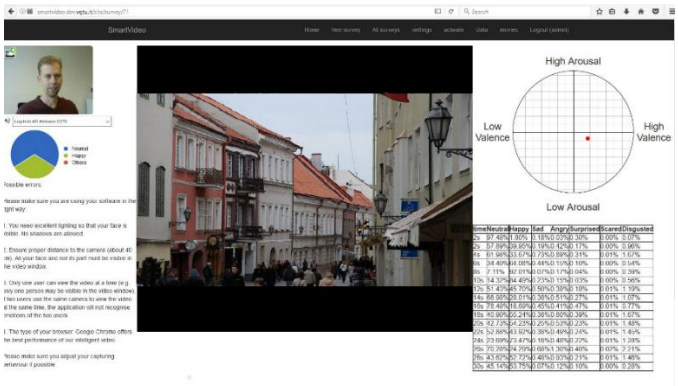


Figure 5. Emotions, valence and arousal analysis results using the FaceReader 7.1 with additional remote photoplethysmography module

Fig. 5 shows a computer screenshot taken during an experiment as part of this research. The face of the passerby taking part in the experiment can be seen in the upper left-hand corner, and a real-time pie chart of the passerby's emotions appears right below it. The table at the bottom right shows these real-time emotions in numbers. Above the table, a circumplex model of emotion [14] captures the passerby's real-time valence and arousal data. The upper right-hand part of Fig. 5 displays the arousal (high to low) and valence (pleasure to displeasure) circle. The top right-hand quarter of the circle shows positive emotions with high arousal and high valence (e.g. happiness). The top left-hand quarter shows negative emotions with high arousal and high valence (e.g. anger). The results are summed up in the arousal and valence circle, and the table of emotions (happiness, sadness, anger, surprise, fear, disgust and neutral) to the right of in Fig. 5 shows whether the passerby likes the built environment under analysis, is neutral towards it or dislikes it.

The Recommendations Model

The recommendations model provides recommendations to various stakeholders (on the effective management of spaces to attract residents, businesses, tourists, cultural operators, events etc.) on ways to improve sustainability, effective regeneration and adaptive reuse of a particular built environment asset.

Stakeholders (e.g. communities, businesses, developers, architects, contractors, landowners, environmentalists and consultants) find built environment spaces with positive emotional charge very attractive, and they are very popular with residents. People often prefer to spend their free time in places with positive emotional charge, and businesses often seek to open outlets and offer products and services at locations where visitors have high valence.

Tejeda-Lorente et al. [38] examine several different methods (content-based, collaborative, demographic, knowledge-based, context-based and hybrid) for generating personalized recommendations. Here, the content-based filtering approach was applied. The basis of the recommendations model is a database of comprehensive information about the alternatives under analysis and a summary of the consumer's priorities.

The recommendations model applies collaborative filtering and offers tips on environmental quality (pollution and noise) and ways to create healthy and safe homes. Information on air pollution (SO_2, KD_{10}, CO, NO_2) and noise pollution is available (see http://iti3.vgtu.lt/ilearning/zemelapis.aspx) for certain locations in Vilnius.

Initially, a user determines the levels of pollution and noise at a desired site and their permitted standards. This information can serve as the basis when the user selects recommendations for how to reduce the specific levels of pollution and noise (SO_2, KD_{10}, CO, NO_2 and noise). The recommendations model suggests a selection of questions that are most relevant for a user. When the user selects the most relevant answers, the recommendations model supplies recommendations (see Figure 6).

The recommendations model is regularly updated to reflect the MICROBE global practices and main global trends [1, 39]. Samples from the recommendations model database are provided below. Better urban and transport planning can reduce cardiovascular disease and mortality by promoting physical activity, cutting air and noise pollution and heat island effects, and creating more green spaces [39]. The rich usually enjoy better urban environments (less air pollution, noise and crowding) than the poor [1]. There is a link between built environment measures (e.g. mixed land use, connectivity, walkability and physical activity), environmental exposures (e.g. green spaces, air pollution and noise), and cardiovascular disease and mortality, and this link is supported by strong evidence [39]. The European Union seeks to create 3D noise maps of its cities, railways and airports. Armed with such data, politicians and the public can gain a better understanding of noise and make

more meaningful contributions to urban development and noise action schemes that were previously limited to experts. Residents of Paris, for example, can now look up noise levels online, and can view data for their street or even for the façade of their apartment [39].

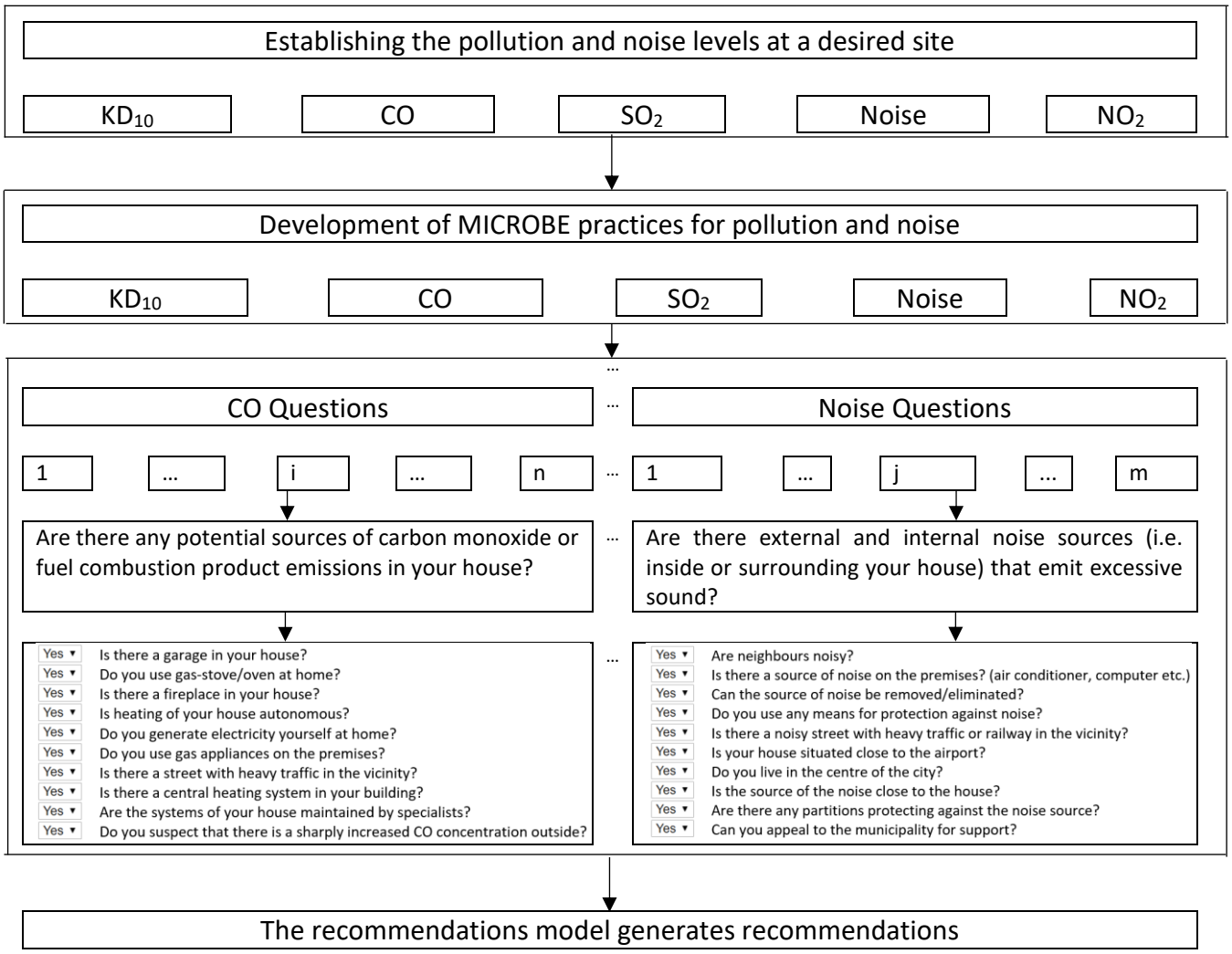


Figure 6. The recommendations model applies collaborative filtering and offers tips on pollution and noise

The Decision Support and Expert Subsystem

The decision support and expert subsystem is a system for modeling built environment alternatives. This subsystem stores and processes data from various sources by applying different mathematical, statistical, multiple criteria, biometrics and affective computing models. Next, it supplies the user with data that are necessary for compiling, analyzing and assessing possible built environment alternatives for decision making. Finally, it derives results and stores them. In this way, the decision support and expert subsystem permits a user to transform a huge amount of data into informational announcements, which are necessary when analyzing issues relevant to the built environment and when making a decision. The modeling performed with this subsystem in the investigation of an object of the built environment (or its composite parts) shows how the object (or its composite parts) will change as the environment surrounding it changes. This subsystem

therefore allows individuals or groups to simulate and visualize a built environment research object and its parts. The knowledge bases of the decision support and expert subsystem store and develop tacit and explicit knowledge and experience accumulated by experts and users of the built environment, which are then used in analyzing and modeling the built environment object under investigation (or its component parts). This subsystem supplies the results of analysis of the built environment in digital, textual and graphic (schemes, graphs or diagrams) format.

The decision support and expert subsystem consists of the multiple-criteria built environment analysis sub-system, the healthy built environment multiple-criteria analysis subsystem, the effective regeneration and adaptive reuse decision support and other subsystems.

7. Case Study 1: MICROBE and its Practical Application in Vilnius

Detailed plans of a city's layout are often drawn up to improve the living conditions for residents. In Lithuania, efforts are made to engage in discussions with residents, and there is a requirement for public deliberation before the construction of any building. The community's (public) interest in town planning within Lithuania includes the community's quality of life, grounded in its objective needs; informing the community; its participation in decision making etc. The permissible duration for familiarization with documents related to territorial planning at state level is no less than two months, and no less than one month is required for public display of these documents (as per the law on territorial planning in the Republic of Lithuania).

Vilnius Gediminas Technical University and Vilnius Municipality selected their research object for implementation of the ROCK (Regeneration and Optimization of Cultural Heritage in Creative and Knowledge Cities) project to be the Vilnius Old Town, a UNESCO object of cultural heritage, including the key built environment within its security zone, which includes Gedimino Prospect, Pilies St., Švitrigailos St. and Lukiškių Square. These objects are significantly different, and are as follows: (i) the historical Pilies St. (part of the Old Town's urban structure from the 16th century), which both city residents and visitors visit frequently; (ii) Gedimino Prospect, a main city street built during the 19th century modernization of Vilnius and renewed at the beginning of the 21st century, which is used during holidays for events and fairs, allowing for human recreation by becoming a pedestrian and bicycle path (as shown in the attached maps) and (iii) Lukiškių Square, of which up to 8 ha is under maintenance; this was known as Lenin Square prior to Lithuania's reestablished Independence, which entailed long and strident debates regarding its reconstruction into a modern, democratic and recreational space. Maintenance work began in 2016 (based on the general plan for the square), and is currently finished. The city planners and the maintenance and management stakeholders of the built environment selected above research objects for implementation of the ROCK, since they wanted to conduct the following research by studying people's emotional states:

- Assessing the quality of above research objects for implementation of the ROCK in terms of rates of attendance and the emotions of the visitors, the age group(s) of the visitors and the durations of their visits.
- Learning which factors are important when developing the built environment and what the recommendations are for better planning of the built environment in order to generate positive emotions and assure health and good attendance.
- Discovering how far the built environment under examination contributes to the satisfaction of city residents.

Vilnius Gediminas Technical University and the Vilnius Municipality placed the equipment subsystem hardware at seven different intersections within Vilnius Old Town and in other places

during implementation of the ROCK project (see Fig. 7). Examples of the equipment subsystem are shown in photographs of the top of Pilies St. (see Fig. 7a) and in Gediminas Prospect (see Fig. 7b). The MICROBE analyzes and rates the built environment in terms of the valence, arousal and emotional states (happy, sad, angry, surprised, scared, disgusted or a neutral state), affective attitudes (boredom, interest and confusion) of passersby and their physiological states (temperature, heart rate, breathing rate, etc.). Real-time mapping, based on this neuro decision table, is needed to display the affective attitudes, emotional and physiological parameters of people passing through the built environment. These affective, emotional and physiological maps serve as references that can offer stakeholder groups personalized tips for upgrading the built environment for greater efficiency and sustainability.

a) b)

Figure 7. Equipment subsystem hardware in Vilnius Old Town: examples of hardware (a) at the top of Pilies Street and (b) in Gediminas Prospect

Biometric/emotional tests on anonymized passersby were performed at the top of Pilies Street and in Gedimino Prospect. Four biometric technologies (tests on the facial emotions, temperature, pulse and respiratory rates of passersby) and data analysis methods were applied, beginning on November 6, 2017. These technologies and methods supply data in various formats, which need to be processed, integrated and analyzed. The aim of this was to analyze the predominate emotional climate at the beginning of Gedimino Prospect and in Pilies Street based on the average affective, emotional and physiological characteristics found in anonymized passersby, their changes on a daily or weekly basis and their various dependencies.

Various technical and technological problems were resolved in relation to the gathering of different biometric/physiological data on passersby during the research. One example is the requirement for a strong Wi-Fi Internet connection for gathering this data. The Internet speed necessary for each set of equipment was around 300 Mb/s; in practice, due to insufficient Internet speed, the measurements of the pulse, breathing frequency and facial temperature of passersby was often interrupted. The equipment was not designed for constant data gathering, and would frequently stop working, meaning that reconnection was necessary either manually or by remote means. The graphs presented below therefore do not represent all of the possible periods (hours or days) for taking measurements. Several of the typical dependencies obtained appear below.

According to Weil [40], the correlation between breathing and emotions is a dramatic example of mind/body unity; when people are anxious, angry or upset, their breathing is always rapid, shallow, noisy and irregular, and slow, deep, quiet, regular breathing simply cannot coexist with emotional turmoil [40]. The tests applied here showed that the average respiratory rate of passersby

was in the range of 12–18 breaths per minute. The lowest respiratory rate observed occurred on Sundays, on November 10 and 24 (see Fig. 8). The correlations found between respiratory rate, happiness and valence were obtained after carrying out all of the data analyses for the entire day (see Fig. 8). The term valence, as used in psychology, especially when discussing emotions, means the intrinsic attractiveness/"good"-ness (positive valence: happiness, pleasure etc.) or averseness/"bad"-ness (negative valence: anger, fear) of an event, object or situation [41].

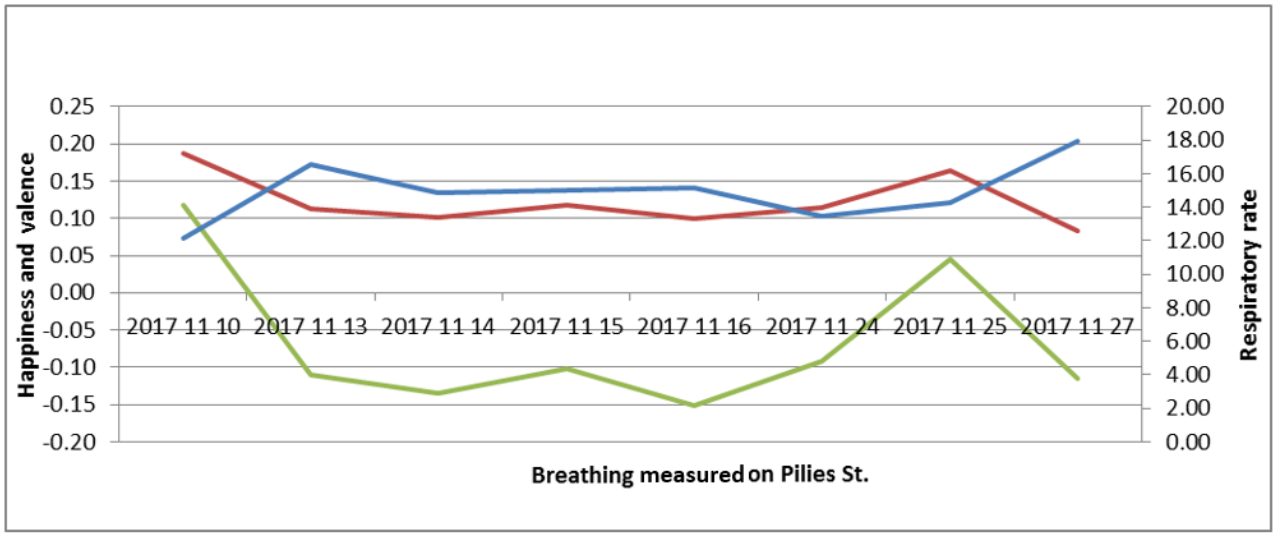
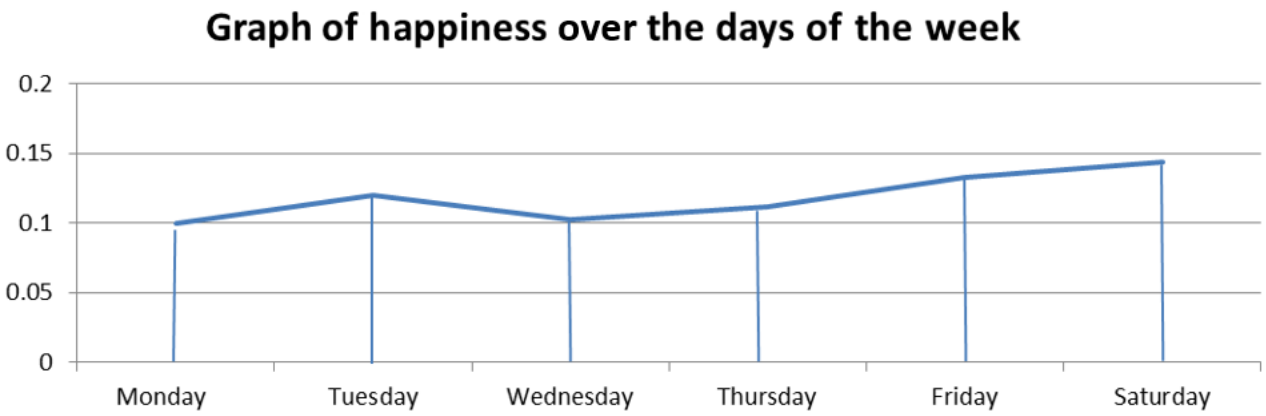


Figure 8. Graph of dependencies between respiratory rate (—), happiness (—) and valence (– – –) of passersby (based on Pilies St. measurements)

Global research indicates that Friday-Sunday is the happiest days of the week (see Fig. 9b). The tests conducted here using remote means (see Fig. 9a) were often similar to tests conducted globally by contact-based means (see Fig. 9b). For example, Fig. 6a shows the happiness graph for all days of the week, drafted based on more than 200,000 anonymized measurements. Fig. 9b shows a similar graph based on relevant global data.

a)



b)

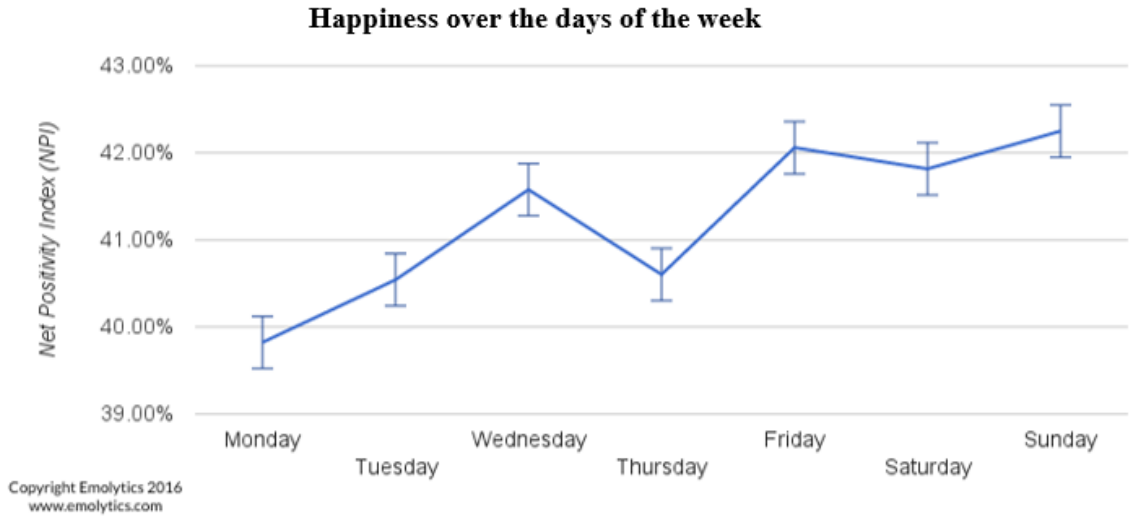


Figure 9. Tests by project partners using *remote means*: (a) graph of happiness over the days of the week, drafted based on more than 200 million anonymized measurements. These are relatively similar to tests using *contact-based means* carried out worldwide: (b) graph of happiness over the days of the week.

For instance, when analyzing the dependency of valence on respiratory rate (Fig. 10), a connection between these parameters is noticeable. The data were analyzed every hour and every three hours. Fig. 10 shows the direct dependency of respiratory rate on valence (direct correlation 0.50278). Thus, one possible conclusion is that a respiratory rate quickens as valence increases, due to various environmental factors (based on analyzing the received data every hour).

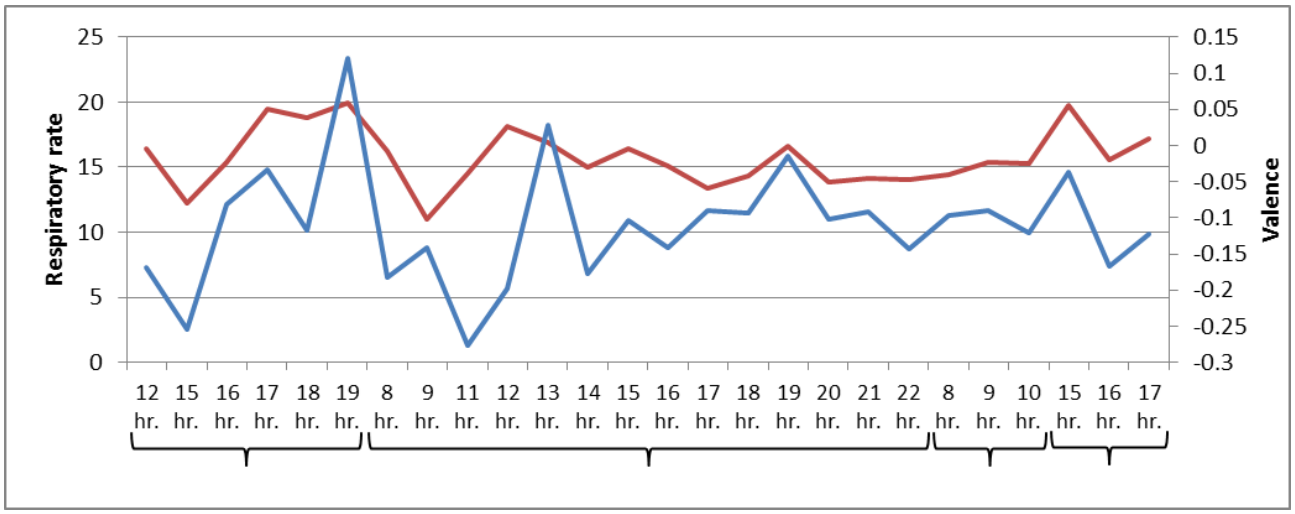


Figure 10. Graph of the relationship between valence (—) and respiratory rate (—) (r=0.50278) using data on anonymized passersby (measured at Pilies St. site)

Briefer et al. [42] found that respiration rate increased with increasing arousal and heart rate, independently of the valence of the situation. The research conducted in this study also arrived at similar results. Three responses—arousal, heart rate and respiratory rate—were measured at Pilies Street and Gedimino Avenue, and in December and January, the values recorded at Gedimino

Avenue were higher than those recorded at Pilies Street. The chart in Fig. 11 compares these results, and clearly shows that in December 2017, the values of arousal (0.3942), heart rate (78) and respiratory rate (16.40) recorded at Gedimino Avenue were higher than those recorded at Pilies Street (arousal 0.3934, heat rate 77, and respiratory rate 16.02). A similar trend was observed when analyzing the values recorded in January 2018.

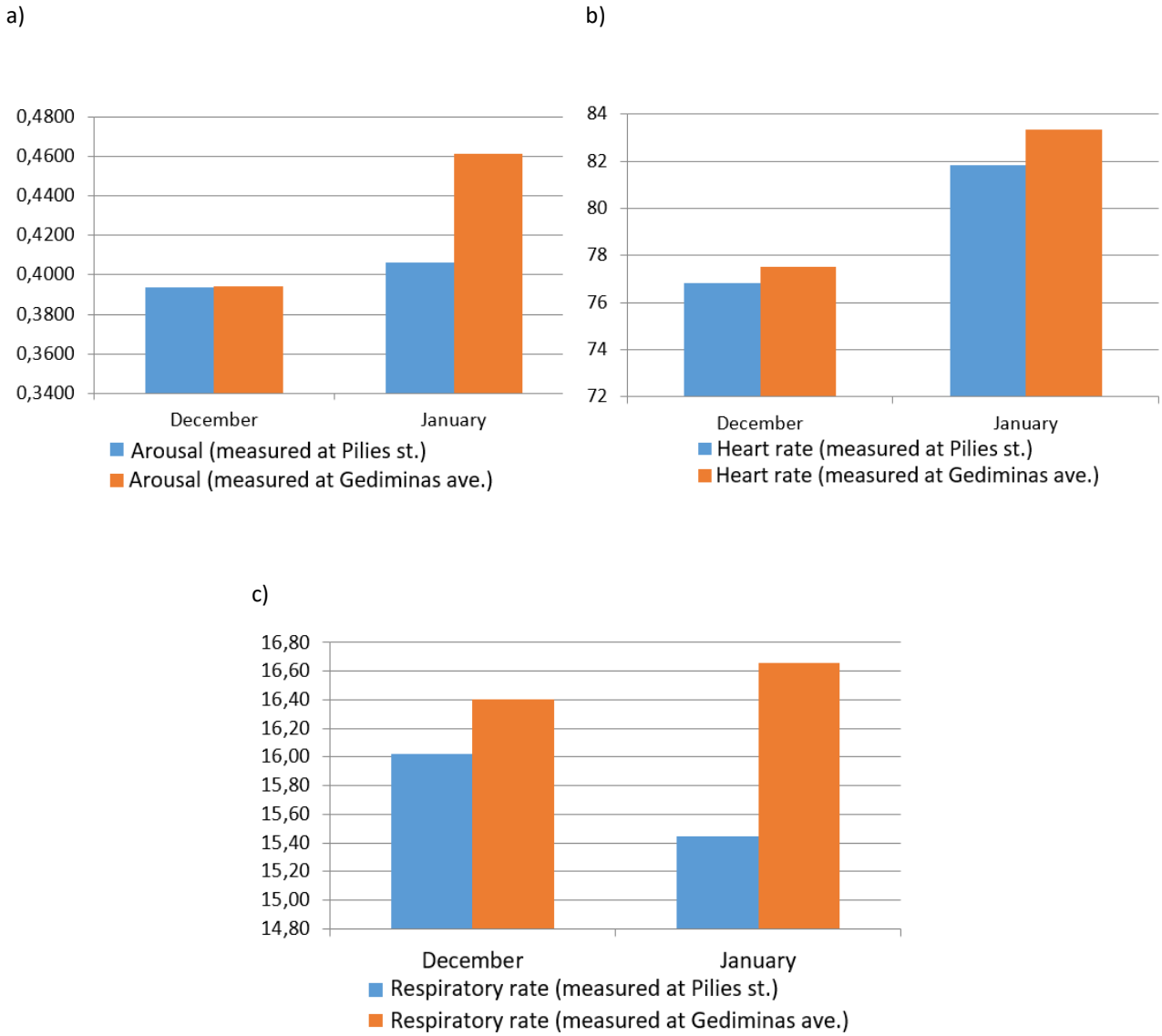


Figure 11. Values of arousal, heart rate and respiratory rate recorded at Pilies Street and Gedimino Avenue sites: comparison between December (2017) and January (2018)

Calculations of the average dependencies of emotions, respiratory rate, heart rate and facial temperature on climate conditions (temperature, humidity, rainfall and pressure) are based on the data gained from anonymized passersby at the top of Pilies St. and in Gedimino Prospect (see Fig. 11 b, c).

The effects of low humidity can be especially dramatic in winter, when low moisture content induces stress upon the nasal-pharynx and trachea [43]. This may explain why Richards, Marriott

[43] found negative correlations between relative humidity and winter absenteeism in a number of Canadian schools. The research conducted for this study also gave similar results. First, an analysis of the dependency of happiness and humidity was performed over a 17-day period (see Fig. 12). It was established that as humidity increased during the winter, the happiness of passersby also increased. The data analyzed during this research involved a total of 0.864 terabytes (TB).

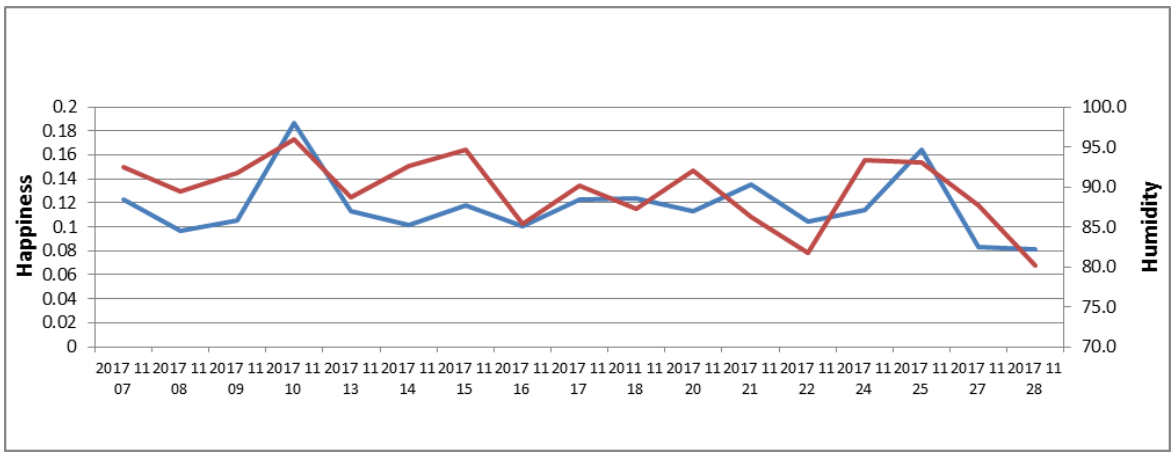


Figure 12. Graph of the dependency of happiness on humidity (r=0.5592) based on measurements at Pilies St. over 17 days:
- average happiness of passersby (%), by day of the analysis;
- average humidity (%), by day of the analysis.

Fig. 13 presents a graph showing the dependency between heart rate, valence and happiness data, as measured on Pilies Street.

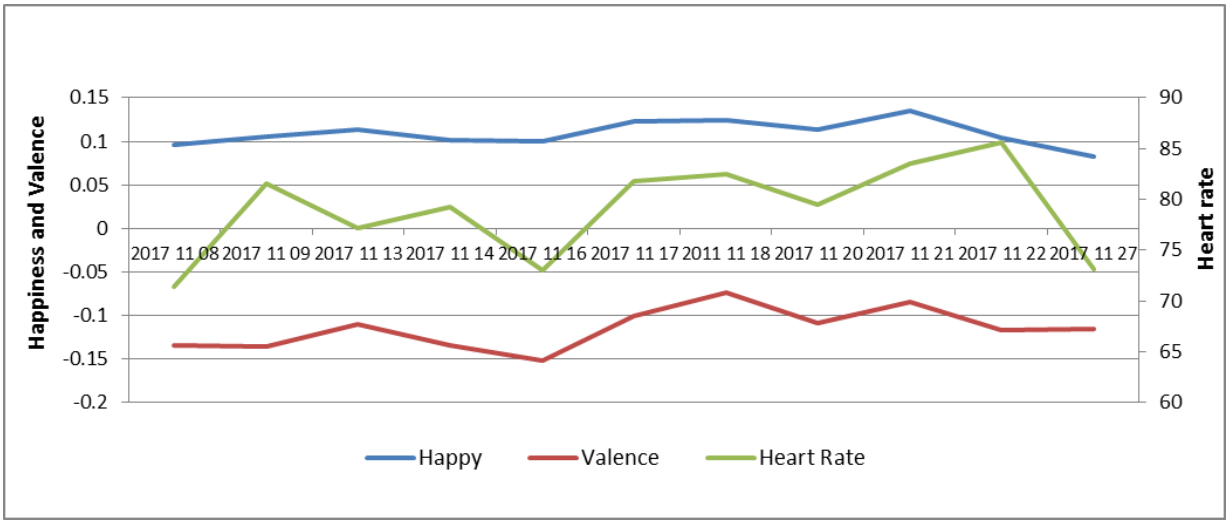


Figure 13. Graph of heart rate, happiness and valence for passersby (measured at Pilies St. site)

8. Case Study 2: Multiple-Criteria Analysis of Municipal Districts in Vilnius

We compared six Vilnius municipal districts (Antakalnis, Naujamiestis, Old Town, Žirmūnai, Žvėrynas and Šnipiškės) in this Case Study by applying INVAR [44] method.

The city planners and built environment maintenance and management stakeholders compiled a system of criteria and a matrix of preliminary data describing the district under deliberation, based

on their experience and on an analysis of the relevant literature. A multiple-criteria assessment of the districts under deliberation was performed with the help of the decision support and expert subsystem, and the results are presented in Table 4. Upon completing the calculations, a list of districts was established in order of priority: $Q_6 < Q_4 < Q_5 < Q_1 < Q_2 < Q_3$. The Old Town district was in first place (utility degree 100%); the Naujamiestis district took second place (utility degree 68.86%); and the Antakalnis district took third place (utility degree 38.94%, lower than that of the Old Town district) (see Table 4).

Table 4. Multiple-criteria analysis of municipal districts in Vilnius

Quantitative and qualitative information related to municipal districts in Vilnius										
	Criteria describing the municipal districts	*	Measuring units	Weight	Comparison of municipal districts					
					Antakalnis	Naujamiestis	Old Town (Senamiestis)	Žirmūnai	Žvėrynas	Šnipiškės
					a_1	a_2	a_3	a_4	a_5	a_6
Economic criteria	1.Average property price	-	Euro./m^2	0.3478	1,762.51	1,953.06	2,595.44	1,721.30	2,131.2	1,912.06
	2.Number of jobs per 1.000 residents	+	Number	0.1539	18.20	94.60	49.20	37.90	10.40	21.50
Social criteria	3.Number of educational institutions (except kindergartens)	+	Institutions/1.000 residents	0.1342	0.4366	0.5596	0.9256	0.2588	0.5416	0.2607
	4.Number of places in kindergartens	+	Number	0.1025	1821	1479	1036	2725	1001	881
	5.Number of healthcare institutions per 1,000 residents	+	Institutions/1.000 residents	0.3424	0.4622	0.3444	0.4628	0.2804	0.2708	0.0652
	6.Recreational facilities in the neighborhood per 1,000 residents	+	Institutions/1.000 residents	0.114	0.0770	0.3874	0.8227	0.2157	0.7221	0.3911
	7.Annual crime rate per 1,000 residents	-	Number	0.3069	13.9702	31.9817	41.446	16.3036	21.2114	33.9591
Environmental protection criteria	8.Air pollution NO2	-	ug/m^3	0.3179	24.42	11.86	21.95	26.37	23.92	33.72
	9.Noise	-	dB	0.0194	54.58	60.12	56.52	57.69	49.07	41.56
	10.Distance to the city centre	-	km	0.1652	4.6	2.2	0.75	3.8	3.1	2.0
	11.Green spaces (maintained large parks and small green urban spaces)	+	%	0.4976	7.20	1.83	21.66	2.78	1.77	0.21
Historical heritage value criteria	12.Direct use value (direct benefits: income/revenue, residential space, commercial space, industrial space, circulation space, economic activity, etc.)	+	Points	0.5	0.54	0.91	1	0.42	0.73	0.68
	13.Indirect use value (indirect benefits:	+	Points	0.5	0.46	0.82	1	0.35	0.71	0.55

	community image, environmental quality, aesthetic quality, valorization of existing assets, social interaction)									
Sums of weighted, normalized, maximizing indices (municipal district "pluses")					0.3632	0.4218	0.7554	0.2614	0.3249	0.2179
Sums of weighted, normalized, maximizing alternative indices (municipal district "minuses")					0.1819	0.1704	0.2149	0.1817	0.19	0.2187
Significance of the municipal districts					0.5661	0.6384	0.9272	0.4646	0.5192	0.3867
Priority of the municipal districts					3	2	1	5	4	6
Utility degree of the municipal districts (%)					61.06%	68.86%	100%	50.11%	56%	41.71%

Digital recommendation provisions

Digital recommendations were provided with the help of the decision support and expert subsystem for how to increase the effectiveness of the districts. We employed the criteria for the direct use value, consisting of direct benefits: income/revenue, residential space, commercial space, industrial space, circulation space, economic activity, etc. (see Table 5). The Old Town (Senamiestis) district (a_3), which holds the status of cultural heritage, was evaluated as the MICROBE in terms of the criterion of the direct use value ($x_{12\ 3}$=1) criteria based on the data in Table 4. The direct use value for the Antakalnis district (a_1, $x_{12\ 1}$=0.54) needs to be increased by 85.19% through various means in order to reach the assessment for the Old Town district (a_3, $x_{12\ 3}$=1). In this case, the assessment for the Antakalnis district would increase by 12.1631% in the overall assessment (see Table 5).

Table 5. Digital recommendations matrix, a fragment

Quantitative and qualitative information pertinent to alternatives									
Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives Possible improvement of the analysed criterion by % Possible market value growth of alternatives by % as first impacted by criterion value growth					
				Antakalnis	Naujamiestis	Senamiestis	Žirmūnai	Žvėrynas	Šnipiškės
• • •									
Direct use value (direct benefits: income/revenue, residential space, commercial space, industrial space, circulation space, economic activity, etc.)	+	Points	0,5	0,54 (85,19%) (12,1631%)	0,91 (9,89%) (1,4121%)	1 (0%) (0%)	0,42 (138,1%) (19,7178%)	0,73 (36,99%) (5,281%)	0,68 (47,06%) (6,7192%)
Indirect use value (indirect benefits: community image, environmental quality, aesthetic quality, valorisation of existing assets, social interaction)	+	Points	0,5	0,46 (117,39%) (16,7616%)	0,82 (21,95%) (3,1343%)	1 (0%) (0%)	0,35 (185,71%) (26,517%)	0,71 (40,85%) (5,832%)	0,55 (81,82%) (11,6823%)

*- The sign + (-) indicates that a greater (lesser) criterion value corresponds to a greater (lesser) significance for stakeholders

Value optimization

The indirect use value criterion (indirect benefits: community image, environmental quality, aesthetic quality, valorization of existing assets, social interaction) were also analyzed. The goal was to establish, what the indirect use value $x_{131\ cycle\ e}$ must be for the Antakalnis district (a_1) to be equally competitive as the other districts under comparison ($a_2 - a_6$) based on an assessment of all their positive and negative features. It is possible to optimize any one of the criteria or its composite parts using the INVAR [44] method. The optimization of the score of the indirect use value will serve as an example (see Table 6). The determination of the optimized score $x_{131\ cycle\ e}$ for the indirect use value under valuation a_1 appears in Table 6. Table 6 shows that the inequality was unsatisfactory for the first 140 cycles. The score x_{131} was increased in every cycle (from $x_{131\ cycle\ 0}$ = 0.46) by a value

of 0.1 until the inequality was satisfied ($x_{131\ cycle\ 142}$ = 0.62). In this case, we optimized the indirect use value and determined how to improve the value of the Antakalnis district to make it equally competitive with the other districts under comparison.

Table 6. Required value of the $x_{131\ cycle\ e}$ score for the district of Antakalnis (a_1) to be equally with the other districts under comparison (a_2- a_6)

Approximation cycles	Indirect use value $x_{131\ cycle\ e}$	Utility degree N_{1e}	Utility degree N_{2e}	Utility degree N_{3e}	Utility degree N_{4e}	Utility degree N_{5e}	Utility degree N_{6e}	*	**
0	0.46	61.06%	68.86%	100%	50.11%	56%	41.71%	62.96%	|-1.90| >0.02 %
…	…	…	…	…	…	…	…	…	…
140	0.6	63.01%	68.79%	100%	50.17%	55.92%	41.63%	63.25%	|-0.24| >0.02 %
…	…	…	…	…	…	…	…	…	…
142	0.62	63.28%	68.78%	100%	50.18%	55.91%	41.63%	63.30%	|-0.02| = 0.02 %

* (N_{2e} + N_{3e} + N_{4e} + N_{5e}+ N_{6e}) ÷ 5

**Inequality used to determine whether the calculation of the revised value $x_{162\ cycle\ e}$ under valuation a_2 is sufficiently accurate.

Hypothetical calculation of indirect use value for the Žirmūnai district

Another research task was to establish a hypothetical indirect use value ($x_{134\ cycle\ e}$) for the Žirmūnai district (a_4) by applying INVAR method [44]. This value was needed to allow this district to rise one position higher in its overall assessment, i.e. from fifth to fourth place in the list of districts (a_1–a_3, a_5, a_6) considering all the indicators under analysis. The calculations performed appear in Table 7.

Table 7. Hypothetical calculation of the indirect use value for the Žirmūnai district

Approximation cycles	Indirect use value, $x_{514\ cycle\ e}$	Utility degree (N_{4e}) for the Žirmūnai district	Rank
0	0.35	49.86%	5
…	…	…	…
150	0.5	52.16%	5
…	…	…	…
400	0.75	55.65%	5
…	…	…	…
430	0.78	56.04%	4

The indirect use value for the Žirmūnai district was 0.35 ($x_{134\ cycle\ 0}$) based on expert assessments (see Table 7). The Žirmūnai district took fifth position in the overall assessment of the districts under comparison. Table 7 shows that the Žirmūnai district remained in fifth position, even after 400 approximation cycles. However, with an increase in the indirect use value of 2.23 times (up to $x_{134\ cycle\ 430}$=0, 78), the utility degree (N_{4e}) for the Žirmūnai district is 56.04%, allowing it to rise from fifth to fourth place.

9. MICROBE Correlation Subsystem (Correlation Matrix Subsystem)

The MICROBE correlation subsystem is used to analyze various correlations between metrics of the human-centered built environment and their influence on people. Two metrics (variables) are

necessary to perform this statistical analysis. This subsystem assisted in establishing over 20,000 average and strong correlations. One matrix of compiled correlations appears in Table 8, and this is applied to examine the dependence among numerous metrics (variables). The outcome is a table of the correlation coefficients among all metrics (variables). The correlation matrix of m metrics C_1, ..., C_i, ..., C_m is the $m \times m$ matrix of which i, j access is the correlation coefficient (C_i, C_j). The correlation matrix is symmetric, since the correlation coefficients between all pairs of metrics (variables) C_i and C_j are the same as those between C_j and C_i.

One of the main tasks involved in compiling a correlation matrix involves establishing whether the correlation coefficients are positive (↑), negative (↓) or both positive and negative (↑↓). For example, if a given metric rises as another declines, the correlation coefficients will be negative; the interdependent correlation coefficients between positive (happy) and negative emotions (angry, sad, scared, disgusted) are always negative. As these positive and negative emotions strengthen, the heart rates and breathing rates (RPMs) of the passersby also increase, and as these positive and negative emotions weaken, the heart rates and breathing rates decrease. The correlation coefficients of certain variables (valence and surprise) may be both positive (↑) and negative (↓). For instance, when a person is positively surprised, this constitutes a positive emotion, whereas a negatively surprise gives rise to a negative emotion. Surprise may involve several valences (i.e. negative/positive, unpleasant/neutral/pleasant).

When compiling the correlation matrix, it was necessary to compare the signs of the correlation coefficients calculated by the project coordinator and partners and other researchers (to determine whether the correlation coefficients were positive [↑], negative [↓] or both positive and negative [↑↓]). Table 8 shows the signs of the correlation coefficients from the studies conducted by other authors, immediately following the correlation coefficients calculated here, and it can be seen that these correspond.

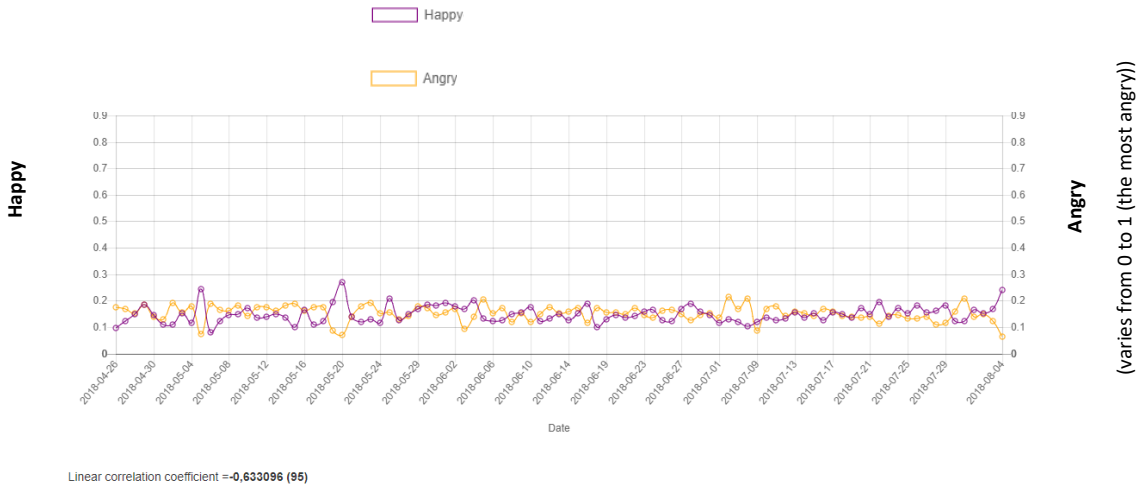
The correlation coefficient between happiness (C_1) and anger (C_2), which was measured over 95 days, is equal to $r_{12} = -0.633096$. This interdependency between happiness and anger is shown in Figure 14a in a graphic representation. Calculations for the correlation coefficient between happiness (C_1) and sadness (C_5) were based on data gathered over 143 days, and the coefficient is $r_{15} = -0.714824$ (see Figure 14b). Figure 14c shows a graph the dependency between anger and O_3 (ozone) measured over 118 days, which equals $r = 0.566964$. Figure 14d shows the dependency between average wind speed and heart rate, which was measured over 18 days; this coefficient equals $r = 0.536366$.

Table 8. Overall average correlations of emotions and physiological parameters of passersby, measured in Vilnius

	Happy	**Angry**	**Valence**	**Arousal**	**Sad**	**Scared**	**Disgusted**	**Heart Rate**	**Surprised**	**RPM**
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Happy, C_1		-0.521545 (91) -0.595601 (94) ↓ [84, 85]	0.718470 (136) 0.728810 (134) ↑ [86, 87]	0.612241 (19) 0.523392 (17) ↑ [86, 87]	-0.603130 (119) -0.621226 (116) ↓ [84, 91]	-0.531560 (13) -0.524357 (13) ↓ [84, 95]	-0.556746 (20) -0.749854 (19) ↓ [88, 98]	0.549774 (24) 0.527523 (23) ↑ [102, 103]	0.611065 (140) 0.630683 (135) -0.602526 (19) -0.807281 (16) ↑↓ [106]	0.530826 (10) 0.506728 (9) ↑ [109]
Angry, C_2		IIIIIIIIIII	-0.571989 (94) -0.604487 (94) ↓ [35, 86, 88]	0.641600 (44) 0.738717 (20) ↑ [35, 86, 89]	0.532036 (46) 0.526728 (46) ↑[84, 85]	0.500834 (58) 0.526444 (55) ↓↑ [84, 95]	0.647792 (140) 0.685516 (137) ↑ [84, 88]	0.521710 (14) 0.601824 (13) ↑ [85, 103]	0.504536 (20) 0.504472 (19) -0.614475 (137) -0.654553 (137) ↑↓[106, 107]	0.567738 (8) 0.521353 (9) ↑ [85, 109]
Valence, C_3			IIIIIIIIIII	-0.544776 (112) -0.523196 (110) 0.582019 (20) ↑↓ [86, 90]	-0.600603 (140) -0.604028 (139) ↓ [92, 93]	-0.50372 (11) -0.522741 (18) ↓ [93, 96]	-0.554166 (48) -0.532177 (47) ↓ [98] ↑ [88, 99]	-0.502520 (33) -0.502610 (32) 0.516717 (29) 0.552884 (27) ↑ [103] ↓[104]	0.584949 (140) 0.533928 (140) ↑ [88, 108]	-0.530927 (10) -0.623779 (9) 0.657739 (7) 0.691830 (6) ↑↓ [109]
Arousal, C_4				IIIIIIIIII	0.514602 (32) 0.528859 (31) ↓ [87, 94]	0.691503 (19) 0.533483 (20) 0.602366 (22) ↑ [93, 94]	0.559046 (38) 0.560846 (37) ↑ [88, 99]	0.512316 (17) 0.608152 (15) ↑ [103, 104]	0.505236 (135) 0.636252 (125) -0.643510 (38) -0.569011 (37) ↑↓ [88, 106]	0.506512 (12) 0.539340 (11) ↑ [109] ↓ [110]
Sad, C_5					IIIIIIIIIII	0.594175 (19) 0.595467 (18) 0.628488 (16) 0.568046 (16) ↑ [84, 97]	0.504701 (20) 0.599640 (19) ↑ [84, 98, 100]	0.653532 (10) 0.506879 (13) ↑ [102] ↓ [104]	-0.501771 (103) -0.520776 (102) 0.514290 (17) 0.568024 (16) ↑↓ [106, 107]	0.646410 (17) 0.512487 (17) ↓ [109, 110]
Scared, C_6						IIIIIIIIIII	0.506773 (38) 0.555596 (19) ↑ [84, 101]	0.618789 (16) 0.506435 (16) 0.551173 (15) ↑ [88, 103]	0.672880 (140) 0.672785 (139) -0.528862 (122) -0.528862 (121) ↑↓ [106] ↓ [95]	0.600705 (15) 0.539613 (15) 0.662005 (15) ↑ [109, 111]
Disgusted, C_7							IIIIIIIIIII	0.588618 (19) 0.547014 (19) ↑ [88] ↓ [104, 105]	-0.696314 (137) -0.635466 (139) ↓ [84, 88]	0.505889 (14) 0.538688 (13) 0.662005 (15) 0.600705 (15) ↓ [110]
Heart Rate, C_8								IIIIIIIIIII	0.506647 (18) ↑ [103, 109]	0.735946 (13) ↑ [112]

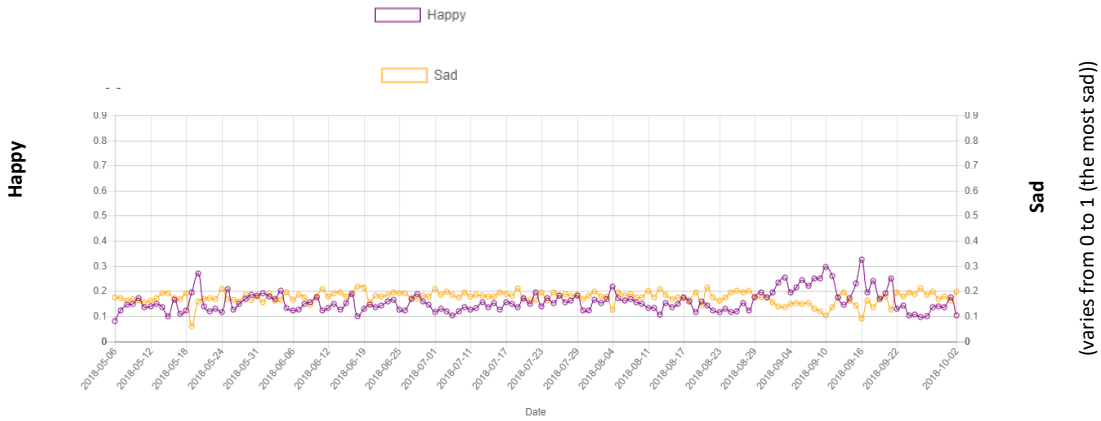
Surprised, C_9									IIIIIIIIIII	0.549239 (13) 0.539770 (13) ↑ [113]
RPM, C_{10}										IIIIIIIIIII
	Happy	**Angry**	**Valence**	**Arousal**	**Sad**	**Scared**	**Disgusted**	**Heart Rate**	**Surprised**	**RPM**

a)



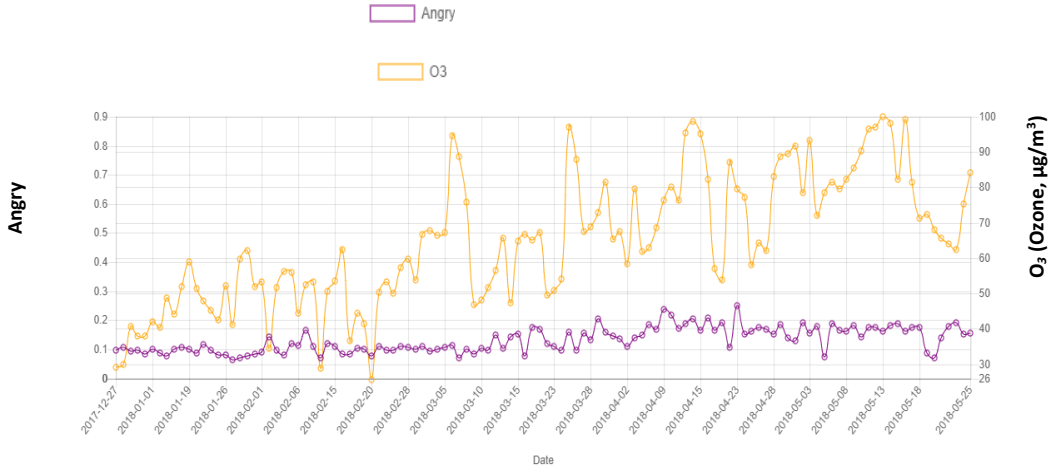
Linear correlation coefficient =**-0,633096 (95)**

b)



Linear correlation coefficient =**-0,714824 (143)**

c)



Linear correlation coefficient =**0,566964 (118)**

d)

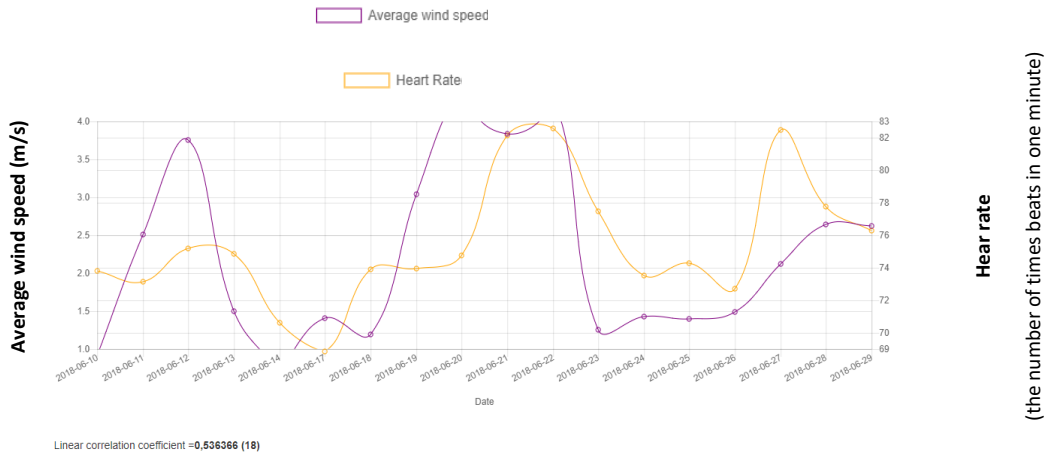


Figure 14. Graphs of dependencies between measurable variables: a) between happiness and anger; b) between happiness and sadness; c) between anger and O_3 (ozone); and d) between average wind speed and heart rate

Studies conducted by other authors in this field appear in Table 8 in an effort to provide a broader explanation. The interdependencies between arousal, valence, various positive and negative emotions, heart rate and breathing rate were highlighted in these studies. The research conducted here indicated similar tendencies.

The circumplex model of emotions [14] tracks passersby in real time, captures valence and arousal readings and creates the arousal and valence circle on a scale from high to low, in the case of arousal, and from pleasure to displeasure, in case of valence. This circle can be used to summarize the results: its top left-hand quarter shows negative emotions with high arousal and high valence (e.g. anger) and its top right-hand quarter shows positive emotions with high arousal and high valence (e.g. happiness).

The previous study [25, 26] suggests that people who are happy have a lower heart rate than those who feel sad. Anger produces arousal, which is a powerful physiological state [2]. Some researchers have preferred to use the mean heart rate as an established and popular indicator of freezing over other, less-accepted indices such as heart rate variability, where arousal rather than valence may be the trigger [26]. Faster heartbeats are highly correlated with the level of mental arousal [7]. Fear and happiness stimuli produced a similar heart rate pattern; the only difference was that fear caused a higher increase in heart rate than happiness [7].

Many external and internal stressors are reported to cause an increase in breathing or minute ventilation [19]. High arousal and unpleasant stimuli cause a decrease in inspiratory time and breath duration [6]. Shallow, fast breathing, for instance, indicates tension, while deep and fast breathing is a sign of excitement accompanied by happiness, anger or fear. Relaxed individuals often have deep and slow breathing, while shallow, slow breathing indicates a calm or negative state [4]. Compared to low-valence emotions, high-valence emotions correspond to more stable respiration values [4].

Surprise is treated as a neutral emotion, since depending on the context, it may result in either a negative or positive appraisal [22].

Many prior studies have categorised emotions based on arousal levels (happiness is a high-arousal emotion, whereas sadness falls into the domain of low arousal) [8]. Anger, for instance, could be classified as a negative valence, high arousal emotion [9]. Anger is triggered by thoughts of blame, frustration, or interpersonal provocation, and is a negative emotion that produces arousal,

a powerful physiological state with an increase in peripheral vasoconstriction and cardiac output [2].

Negative expressions such as sadness, fear, anger and disgust signify potential harm or threat, while a happy expression signals rewards and benefits, and a surprised expression is a sign of motivational and emotional ambiguity [10]. In the main, the basic emotions tend to be more negative than positive (e.g. fear, sadness, anger and disgust) [24].
Our research results are consistent with above findings.

10. Assessing the Accuracy of the MICROBE Through Verification and Validation

The video neuroanalytics, historical, recommendations, decision support and expert subsystem databases contain data gathered from the equipment subsystem. All of the data collected were checked using two stages: validation and data verification.

Lewinski et al. [45] validated FaceReader by using two publicly available and objective datasets on basic human emotions and evaluating the accuracy of recognition of facial expressions. In 2005, matching scores of 89% were reported for FaceReader. Lewinski et al. [45] tested version 6.0, and discovered that FaceReader recognized 88% of the target emotional labels in the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP) and Amsterdam Dynamic Facial Expression Set (ADFES). The Facial Action Coding System (FACS) index of agreement averaged 0.69 for both datasets, meaning that the rate of human emotion recognition was 85%. Lewinski et al. [45] also computed the accuracy of recognition of basic emotions by humans for the two datasets and determined that the accuracy was 87% for ADFES and 82% for WSEFEP. These authors report that over the past decade, FaceReader has proven to be a reliable indicator of facial expressions revealing basic emotions, and that when used with with FACS coding it has the potential to be similarly robust. For FaceReader 6.0, researchers have reported a general accuracy of 88% on basic emotions. The FaceReader index of agreement for FACS accuracy is 0.69 [45]. Other researchers report similar results for the validity and accuracy of FaceReader and hold similar views on Noldus Information Technology, the manufacturer of the equipment.

The infrared camera FLIR A35SC has an accuracy of ±2% (FLIR) and a thermal sensitivity of <0.05°C. The camera was calibrated/verified by the manufacturer and its calibration certificate confirmed the measurement results. Every 12 months, thermographic cameras are subject to metrological verification to ensure there are no deviations in the error rate from the parameters set by the manufacturer.

As part of the data validation, the thermal data transferred to MICROBE were cleaned to ensure their quality (accuracy, update status, completeness, consistency across data sources, relevance, reliability, appropriate presentation, meaningfulness, accessibility) and to check their correctness and fitness in the context of the built environment. This cleaning exercise revealed that some data were inaccurate, and this issue was fixed where possible; when this was impossible, inaccurate, incomplete, rounded, heaped, censored and missing data were removed. A selected range underwent thermal image segmentation, involving analysis of the average temperature of a human face. Only the average crowd face temperature was measured in this way, thereby eliminating unnecessary temperature values that could distort the final results of the study. Later, during the data processing stage, the average background temperatures of people outside the observation zone were also eliminated.

The specifications were developed and the preliminary development of the intelligent model base was completed. An iterative model was applied to verify and validate the intelligent model

base. Then the intelligent model base and its models were verified and validated to ensure they were valid and accurate. This verification and validation was applied to the recommendations model, the decision support and expert subsystem and the MICROBE (the Affect-Based Built Environment Video Analytics). This verification process confirmed that the intelligent model base and its models fully corresponded to the specifications and the MICROBE concept. The expert method was applied in this task, and logic flow diagrams were compiled that outlined the potential possibilities of modular use. The subjective reviews method was also applied to validate the intelligent model base and its models.

Another important source of input for simulations of emotional states of a crowd were expert observations, which were sought as part of the validation and verification process. Eight facilities management specialists and eight real estate development experts validated the human affective, emotional and physiological data analysis under real conditions. The affective attitudes, emotional and physiological states data gathered by MICROBE was validated using a questionnaire for containing 18 questions, of which 16 were related to affective attitudes, emotional and physiological states data analysis (e.g. 'Are the aggregate comparisons of the emotions of happiness expressed by passersby correct?'; 'Has MICROBE correctly identified the emotions of the passersby?'; 'Are the correlations between the four parameters (the three human emotions of surprise, anger, arousal, and the relative humidity) correct?'). The remaining two questions were related to the aims of the study ('Are the aims set in MICROBE consistent with those of stakeholders (inhabitants, landowners, urban planners, built environment maintenance and management specialists and businesses)?'; 'Do experts and stakeholders find the results provided by MICROBE interesting?'). Each professional responded to these questions by selecting one option from the following typical four-level Likert scale: strongly disagree (1), disagree (2), agree (3) or strongly agree (4). The SPSS Statistics software package was employed to examine the answers and to compute data frequencies and standard deviations. The 16 questions related to human affective attitudes, emotional and physiological states analysis and the two questions concerning the aims all scored between 3-4 points. Following this exercise, the improvements recommended by the facilities management specialists and real estate development experts were applied, their validation of the human biometric and emotion data in the built environment were considered and the MICROBE was put into practice.

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